UPPER OTTAWA STREET
LANDFILL SITE STUDY

FINAL REPORT

May, 1986

TABLE OF CONTENTS

Page

Letter of Transmittal iv

Acknowledgements v

Executive Summary vi

PART 1

OVERVIEW OF THE PROBLEM 1

CHAPTER 1

INTRODUCTION TO THE REPORT 2

CHAPTER 2

THE HISTORICAL DEVELOPMENT OF THE UPPER OTTAWA STREET LANDFILL SITE 8

CHAPTER 3

PLANNING LANDFILL INVESTIGATIONS: AN OVERVIEW OF GENERAL CONSIDERATIONS AND THE APPROACH USED AT THE UPPER OTTAWA STREET SITE 25

PART 2

RESULTS OF CHEMICAL ANALYSES

CHAPTER 4

CHEMICAL CONTENT OF THE LANDFILL 48

Page

CHAPTER 5

CHEMICAL CONTENT OF LEACHATE, SURFACE WATERS AND SEDIMENTS 65

CHAPTER 6

THE DIRECTION AND RATE OF FLOW OF GROUNDWATER 98

CHAPTER 7

THE CHEMICAL CONTENT OF GROUNDWATER 117

CHAPTER 8

CHEMICALS IN LANDFILL GAS AND SURROUNDING NEIGHBOURHOODS 136

CHAPTER 9

IMPLICATIONS FOR HUMAN HEALTH OF EXPOSURE TO CHEMICALS FROM THE LANDFILL 178

PART 3
HEALTH STUDIES

CHAPTER 10

INTRODUCTION TO THE HEALTH STUDIES 191

CHAPTER 11

A SURVEY OF THE HEALTH OF PERSONS WORKING AT OR NEAR THE UPPER OTTAWA STREET LANDFILL 208

Page

CHAPTER 12

SURVEY OF THE HEALTH OF PERSONS LIVING NEAR THE UPPER OTTAWA STREET LANDFILL. 239

PART 4
CONCLUSIONS AND RECOMMENDATIONS

CHAPTER 13

CONCLUSIONS AND RECOMMENDATIONS 293

List of Figures 324

List of Tables in Text 325

List of Appendices 329

UPPER OTTAWA STREET LANDFILL SITE STUDY

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May, 1986

The Honourable Murray Elston
Minister of Health
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Sir:

On October 21, 1981 pursuant to Section 9 of the Ministry of Health Act, Revised Statutes of Ontario, 1980, Chapter 280, we were appointed as an advisory committee to undertake the following activities and to advise the Minister as to all the facts which may be pertinent to the matter of the Upper Ottawa Street Landfill Site:

1. To investigate the validity of studying, and as appropriate, to recommend to the Minister of Health that studies be undertaken on:
   - (a) the chemical nature of the materials deposited in the landfill site and their changes in that environment;
   - (b) the migration of chemical substances away from the area;

   and to consider the findings of any such studies.
2. To advise the Minister as to the Committee's findings and as to the possible existence at or about the landfill site of a hazard to human health.
3. To consider such other matters brought out in the course of the Committee's activities which the Committee deems relevant to the terms of reference.

We have completed these tasks and we now respectfully submit the conclusions and recommendations.

A.N. Bourns

A.N. Bourns
Chairman

D.R. McCalla **Committee Member**	**A.L. McCallion** **Committee Member**	**J.B. Osbaldeston** **Committee Member**

ACKNOWLEDGEMENTS

We wish to thank sincerely the hundreds of people who live and work in the neighbourhood of the Upper Ottawa Street landfill, and elsewhere in the Hamilton-Wentworth Region, for their support of the Committee's investigation, particularly their participation in the health surveys.

We express our gratitude to Mrs. Hedy Gervais, Mr. and Mrs. Ronald Bridgeland, Mr. Edward Stodulka and Mr. Douglas Stowe, who represented the views of the Upper Ottawa Street Residents' Association and to their consultant, Dr. Steven Safe.

We thank the members of the Advisory Health Group for their invaluable assistance. We wish to cite the especially generous contribution in time and effort of Dr. William Goldberg.

We gratefully acknowledge the devoted services of Mrs. Terry Botermans, our secretary and the research support provided by Mr. Clive Baugh.

Many individuals and firms acted as consultants to the project and we appreciate their contribution in providing knowledge and tackling the difficult research problems that were encountered at every stage of the investigation. We express special gratitude to Dr. Clyde Hertzman, Mr. Michael Hayes, Dr. Joseph Highland, Professor John Cherry, Mr. Nick Sidoruk and Mr. John Martin.

EXECUTIVE SUMMARY

A. BACKGROUND

The Upper Ottawa Street landill is located on the east mountain in Hamilton, Ontario within one km of the face of the escarpment. The Red Hill Creek forms the northern boundary of the site. The landfill sits on fractured bedrock in contact with groundwater, but the aquifer is not used as the local water supply. The prevailing wind direction is from the west away from nearby residential areas.

Extensive residential development began in the mid-1970s, and there are over 1500 households located within 750 metres of the landfill, primarily to the west and north of the site. The neighbourhood also contains two elementary schools, a public works yard, a conservation area, a training facility for firefighters and light industrial development.

From the early 1950s until it was closed in 1980, the landfill received many types of domestic and commercial waste, as well as solid and liquid industrial wastes from the Hamilton region, elsewhere in Ontario and from the United States. What began as a rural quarry dumpsite is now a 30 metre high garbage mound covering about 16 hectares. The mound is covered by an intermediate layer of solid waste materials from the local steel industry and a cap consisting largely of clay, which has been seeded with grass. Leachate is collected from some areas of the landfill by a system of pipes and eventually reaches the city sewage treatment plant. Deep erosion gullies have formed on the steep slopes of the landfill, particularly on the north side where leachate flows directly into the creek. Large volumes of methane gas are being produced and vented through the cover and gas vents installed on the south side of the site.

The amounts and types of wastes buried in the landfill will never be known with any degree of certainty. It is the liquid industrial wastes that are the greatest cause for concern and existing records indicate that millions of litres were deposited at the site during the 1970s. This situation raised alarm among area residents. The practice of onsite burning of wastes was stopped in 1978; the site was closed to liquid industrial waste disposal in January of 1980; a solidification plant for processing liquid wastes, which began operation in 1976-77, was closed in April of 1980; and the final closure of the landfill took place in October 1980.

B. APPOINTMENT OF STUDY COMMITTEE

The Regional Municipality of Hamilton-Wentworth requested the Ontario Ministry of Health to carry out a health study and the Study Committee was appointed to conduct this work. The Committee began to plan its investigation in April of 1981.

The Committee's terms of reference are:

a) to investigate the chemical nature of the materials deposited in the landfill site, changes in the materials in that environment, and the migration of chemicals away from the area;

b) to study the possible existence at or about the landfill site of a hazard to human health;

c) to consider such other matters brought out in the course of the Committee's activities that are relevant to the terms of reference.

It was stressed by the Ministry of Health that the investigation was the first of its kind in Ontario and would need to be conducted in a thorough and comprehensive way so that it would be useful as a prototype that could be applied to future problems at other landfills.

C. STUDY PLAN FOR THE INVESTIGATION

Some of the major obstacles recognized in the development of the study plan include: the lack of knowledge about the types and amounts of wastes deposited at the landfill and the concentrations of compounds to which persons may have been exposed when the site was operating; ready access for the migration of landfill contaminants in the creek which flows through the site or in the fractured bedrock upon which the landfill is situated; and a "difficult to define" exposed population consisting of a small number of workers, plus residents who, for the most part, did not live in the area until 1976.

C1. CHEMICAL CONTENT OF THE LANDFILL

The Committee decided that it was neither practical nor affordable to drill the hundreds of boreholes that would be required to obtain a complete picture of the buried wastes. It was possible, however, to analyze core samples obtained from the drilling work required to replace broken borehole installations. This was done to provide information on chemicals to which people may have been exposed before the landfill was closed and covered and to address the question of whether or not there are chemicals buried in the landfill that are not being detected in landfill gas or leachate at present but could be expected to migrate in the future.

C2. CHEMICAL ANALYSES

The second stage of the investigation was to examine the environment around the landfill. Major attention was given to air, surface water, leachate and groundwater.

C2.1 Air

The Committee identified airborne contaminations as the most important potential route of human exposure to toxic chemicals. The air testing program was designed to obtain information on (1) the chemical content of gas emitting directly from the landfill; and (2) the quality of the air in nearby neighbourhoods. Special attention was given to the analysis of polycyclic aromatic hydrocarbons (PAHs).

A major testing program was also undertaken in conjunction with experiments on the feasibility of collecting and burning landfill gas.

C2.2 Leachate and Surface Water

Organic compounds are likely to be the most dangerous toxic substances contained within the landfill and their identification in the leachate and surface water was considered to have high priority. One reason for this is that a cover has been placed on the closed landfill and, consequently, air tests might not detect many of the compounds to which persons may have been exposed when the landfill was operating. Also, compounds that might not be detected in the air because of their low volatility might be found in the leachate.

An additional important factor calling for extensive leachate analysis is that leachate flows from springs on the mound into Red Hill Creek, thereby potentially exposing people downstream to landfill contaminants. Furthermore, although dilution will be large, it is important to know the extent to which pollutants of a toxic nature are entering the sewage system from the site by way of leachate collection.

C2.3 Mutagenicity Testing

The Committee recognized that a major concern among the workers and residents is the possibility that exposure to landfill chemicals may cause cancer. A decision was made to undertake a program of Ames assays of leachate, air particulates and landfill gas since these assays represent a rapid and economical screening test for potential carcinogens.

C2.4 Groundwater

Because the Upper Ottawa Street landfill sits on fractured bedrock, there was concern that the site might be polluting the groundwater and that a contaminated plume would present serious environmental problems should it seep through the nearby escarpment face. Little is known about the flow characteristics of groundwater in bedrock. A university-based groundwater research institute was retained to conduct an extensive, pioneering study of the hydrogeological aspects of the Upper Ottawa Street landfill. The study involved the measurement of groundwater flow rates as well as extensive chemical analyses to map the contaminated groundwater plume.

C3. HEALTH STUDIES

The third and most critical aspect of the Committee's investigation was the health studies. The plan for the health studies of landfill workers and residents consisted of four components: toxicological assessment of the detected chemicals to assist in designing the health studies and interpreting the results; an assessment of the feasibility of conducting epidemiological investigations; designing the workers study; and designing the residents study.

C3.1 Toxicological Work

The Committee recognized that in order to have as clear a focus as possible for its health studies, detailed toxicological information was needed on the many compounds detected and/or tentatively identified in its analytical work. This involved identifying the most potentially toxic compounds to be targeted in chemical analyses, assessing the types of disease that might be expected if persons had been exposed to certain of these chemicals in sufficiently high levels and for long enough periods of time and assessing the implications for human health of current exposure.

C3.2 Designing Health Studies of Workers and Residents

An Advisory Health Group was established to direct work on designing the health studies. Designing health studies of the type needed was hindered because a) there is no established methodology for such studies, b) the duration of exposure for most residents is less than 10 years, which is too short a time for potential chronic effects such as cancer to be detectable, and c) the likelihood of being able to establish a cause and effect relationship between illness and the landfill is small because of the problems of isolating landfill exposure from other types of chemical exposure.

It was decided to conduct separate health surveys of cohorts of workers and residents involving: questionnaires administered in the respondents' homes by professional interviewers; the use of control groups for comparing the health of landfill workers and residents to similar groups of people elsewhere in Hamilton; and medical chart abstraction studies, which involved examining the medical charts kept by the family doctors of study participants. The study of workers was planned to precede that of landfill residents in order to generate hypotheses from the potentially higher dose exposure of workers that could be tested in the subsequent larger-scale study of residents.

In designing the health studies, particular attention was given to two major problems: the lack of exposure information and the possible bias associated with self-reports of health problems.

In the absence of detailed knowledge about the types and concentrations of chemicals to which workers and residents may have been exposed, the questionnaires were designed in such a way as to detect a wide range of possible health effects related both to the identified chemicals and to chemical exposure generally. The sampling strategies were developed to use duration of residence and proximity to the landfill as indirect indicators of exposure for the residents study, and onsite jobs versus offsite jobs as indirect indicators of exposure for the workers study.

Detailed medical chart abstraction studies were designed in conjunction with health studies of landfill workers and residents for the purpose of addressing recall bias. In the case of the workers study, the objective of the chart abstractions was to verify the accuracy of self-reports of individual respondents. The objective of the residents chart abstraction study was to ascertain the amount of recall bias through a comparison of general trends of over- and under-reporting between landfill residents and controls.

C3.3 Clinical Studies and Laboratory Tests

Clinical and laboratory tests were not included in the health studies because what was known about exposure indicated that diagnostic testing would not be useful. It was decided, however, that physical examinations and other medical studies would be carried out if the results of the epidemiological studies identified health conditions in landfill residents that should be further investigated by the use of such tests.

C.4 MISCELLANEOUS STUDIES

During its investigation, the Committee also conducted limited research into four additional areas; the feasibility of using geophysical techniques to detect containers of chemical wastes that might be buried in the site; a small animal study involving examination of animals trapped on the landfill and tissue residue analysis; a review of student absenteeism records in a neighbourhood and control schools; and an examination of gas company records for unusual complaints for households located near the site. In no case were the findings helpful in providing additional information about landfill chemicals or exposure-related health conditions.

D. CONCLUSIONS AND RECOMMENDATIONS

D1. EXCAVATING THE LANDFILL

The following factors were taken into account in examining the question of whether excavating the landfill would cause more harm than good. Chemical analyses have failed to demonstrate that toxic chemicals in hazardous concentrations are migrating from it. There are the important practical considerations of the enormous size of the landfill, the millions of tons of solid material comprising it, the extension of the base of the landfill below ground level into fractured bedrock, and the lack of a more secure destination in Ontario to which the excavated material could be transported. Also, there would be the almost impossible task of preventing more direct exposure of people to rapid release of high concentrations of compounds during an excavation project that would likely require many months, if not years, to complete.

RECOMMENDATION 1: The Committee recommends that excavation of the site should not be undertaken.

D2. MAINTENANCE OF THE LANDFILL

D2.1 Findings

After an initial slow start, most areas of the landfill mound are now covered with vegetation, which is necessary to protect the underlying cover and to promote the evaporation of precipitation. There are, however, some unvegetated patches requiring further seeding efforts.

There are noticeable problems with numerous areas of leachate seepage, which are caused by the elevated water table within the garbage mound. These seeps are are usually located in erosion gullies.

The infiltration of precipitation into the landfill over many years has caused mounding of the water table to a present height of about seven metres above the surrounding ground level. Until the water mound recedes below ground level, leachate springs will continue to be a problem.

The condition of the cover on the north slope permits the direct infiltration of precipitation into the mound and the continuing discharge of leachate directly into the Red Hill Creek.

The evidence indicates that the leachate collection system is not operating effectively and that most of the leachate is bypassing the collection system and passing into the bedrock below the site.

The unfenced north side of the site, where leachate springs are entering the Red Hill Creek, is the only remaining area of the landfill where there is easy entry for the public.

Maintenance workers, quite properly, have refused to enter the leachate collection manhole until they have received assurance that maximum protection is being afforded by the equipment and protective clothing provided.

D2.2 Recommendations

RECOMMENDATION 2: The Committee recommends that spring and late summer seeding be undertaken each year until the remaining exposed surfaces of the landfill cover are vegetated.

RECOMMENDATION 3: The Committee recommends that the following steps be undertaken each spring and fall to make repairs to the landfill cover:

a) erosion gullies should be lined with a geotextile (i.e., synthetic material used for outdoor construction) and packed with gravel or stone to preserve a surface drainage system;

b) leachate seeps should be connected by french drains to the existing collection pipes on the west, south, and east slopes of the landfill;

c) careful inspection of all parts of the cover should be conducted and repair work should be done until a decline in leachate production and migration is observed and then this spring and fall schedule can be re-examined.

RECOMMENDATION 4: The Committee recommends that the height of the mounded water table be measured annually from boreholes on the northeast corner of the landfill (Sites 15 and 16 on Figure 6 and described in Appendix 2) where previous measurements were taken. Two monitoring wells are currently located at these sites and can be used for this purpose if they are in working condition. If not, new installations will be required.

RECOMMENDATION 5: The Committee recommends examining the feasibility of collecting the leachate that is flowing down the surface of the north slope into the creek and disposing of it in the sanitary sewer.

RECOMMENDATION 6: The Committee recommends that measurements be made and that records be kept of the volume of leachate being collected by the separate systems installed on the west and south sides and to the east of the site.

RECOMMENDATION 7: The Committee recommends that access to the landfill and creek on the north side be restricted by fencing.

RECOMMENDATION 8: The Committee recommends that maintenance workers be protected from skin contact with leachate. The chemical findings on landfill gas indicate that it is unnecessary to wear a protective mask unless work is being done directly on the gas vents themselves. Masks should be provided, however, for those who wish to wear them when working in areas of lower gas concentration. The Committee recommends the use of a self-breathing apparatus and high quality protective clothing for workers who enter the underground collection manhole.

D3. LEACHATE, SURFACE WATERS AND SEDIMENTS

D3.1 Chemical Findings

The effect of leachate on the general water quality (hardness, chloride, ammonia, nitrite, etc.) of the Red Hill Creek can be observed immediately downstream of the site. The effect is not large, however, and by the time the creek reaches Albion Falls, about one km downstream, these general water quality parameters are similar to those upstream of the landfill.

Leachate contains of a number of metals, with aluminum and iron in highest concentrations. In the Red Hill Creek, however, the levels of heavy metals are extremely low and are no higher downstream than upstream of the landfill.

The organics in leachate (which are found in concentrations of low ppm or less) include the volatile aromatic hydrocarbons (such as benzene and toluene), chlorinated hydrocarbons (dichloromethane, dichlorobenzenes), phthalates, tetrahydrofuran and 1,4-dioxane. Polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs) were also detected. These findings suggest the site was not used for the disposal of large volumes of organic chemical wastes.

The levels of organics in Red Hill Creek are not significantly higher downstream than upstream of the landfill.

With the exception of methylphenanthrene, PAH concentrations in creek sediments were actually higher upstream of the landfill than downstream. In contrast, the levels of PCBs in sediment were somewhat higher immediately downstream than upstream from the landfill. At no site did the concentrations of PCBs exceed one ppm.

D3.2 Conclusions and Recommendations

The current risk from exposure to landfill chemicals in surface water and sediments is not significant for two reasons: 1) there is limited opportunity for human contact with these chemicals, and 2) the current levels of contamination are small. With respect to leachate, while there is limited opportunity for exposure, the leachate does contain appreciable amounts of toxic chemicals. These conclusions are reassuring but they only apply if the nature and concentrations of chemicals in the future remain low. Therefore, a monitoring program for leachate, surface water and sediments is required to serve as an early warning of possible increases in the levels of toxic chemicals.

> **RECOMMENDATION 9: The Committee recommends that samples of leachate from the leachate collection manhole (see Site 32 in Figure 6 and Appendix 2) and from two leachate springs on the north slope of the landfill be collected twice annually, during the spring and late summer. Once work has been completed to eliminate surface leachate springs on the north side, a permanent sampling station should be established there for the collected leachate. Samples should be analyzed using the best available methods for quantitative analyses of trace organic compounds. At the present time this is the GC-MS method. The compounds detected in the Committee's work could serve as the target list for these analyses. Analysis should also be capable of detecting "priority pollutants" not detected in the Committee's work.**

> **RECOMMENDATION 10: The Committee recommends that samples of the Red Hill Creek water upstream and downstream from the landfill (see Sites 2 and 22 in Figure 6 and Appendix 2) be collected twice a year, during the spring and late summer, and analyzed using the methods outlined above for leachate.**

> **RECOMMENDATION 11: The Committee recommends that samples of sediments from the Red Hill Creek upstream and downstream from the landfill (Sites 2 and 22) be collected once a year during the late summer and analyzed for polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs) using the best available methods for quantitative trace analysis of these compounds.**

> **RECOMMENDATION 12: The Committee recommends that this monitoring work on leachate, surface water and sediments be conducted as described above for five years. If, at that time, the results indicate a sufficient decrease in the concentrations and numbers of compounds, or if no change is detected, less frequent sampling and analysis could be considered.**

> **RECOMMENDATION 13: The Committee recommends that the monitoring data be reviewed by the appropriate persons in the city and regional governments, by the Ontario Ministry of the Environment and by at least one external consultant. The results should be made public each year.**

RECOMMENDATION 14: The Committee recommends that in the unlikely event that fish are being caught in the Red Hill Creek, appropriate public warnings should be posted advising against their consumption. The reason for this is that many chemicals are concentrated in fish to levels hundreds or thousands of times higher than those of the same chemicals in the water in which the fish live.

RECOMMENDATION 15: The Committee recommends that swimming or playing be prohibited in the Red Hill Creek.

D4. THE GROUNDWATER STUDY

D4.1 Hydrogeology

The study confirmed that the general groundwater flow is from west to east, following the downward slope of the regional water table towards Albion Falls.

It is also concluded that by the time the groundwater reaches the escarpment it is flowing deep within the rock under the base of Albion Falls and does not surface until it reaches Lake Ontario.

It is likely that a 'plume' of leachate now exists in groundwater over the nine kilometre distance between the landfill and Lake Ontario.

D4.2 Chemical Content of Groundwater

Groundwaters in the region are contaminated by chemical substances from the bituminous, hydrocarbon-rich bedrock. These natural contaminants, for the most part, are the same as those found in leachate, surface waters and sediments. This has greatly complicated the mapping of the groundwater plume.

The most serious groundwater contamination occurs within 100 metres of the landfill. Beyond this distance, even in the direction of groundwater flow to the east, landfill contamination becomes indistinguishable from background levels. It is also concluded that the groundwater plume discharging into Lake Ontario is unlikely to have a measurable impact because its chemical content does not appear to be greatly different from that of the natural groundwater.

D4.3 Human Exposure

Exposure to leachate contaminated groundwater is unlikely because drinking water is supplied by city water lines and the groundwater flows at some depth. The closest the groundwater comes to the surface to the west of the landfill where housing is located, is seven to eight metres. On the other hand, groundwater immediately to the east is less than one metre below ground surface.

RECOMMENDATION 16: The Committee recommends that no excavation work be undertaken in the low lying area immediately east of the landfill, and that no housing be constructed there because this area is in the path of leachate migration.

D4.5 Monitoring of Groundwater

While there does not appear to be a public health hazard or a significant environmental risk associated with landfill contamination of groundwater at the present time, this situation may change, especially if there are containers in the landfill that have not yet ruptured. Furthermore, many organic compounds whose identity has not been established are present in the groundwaters.

RECOMMENDATION 17: The Committee recommends the installation of four additional multilevel piezometers for the purpose of long-term monitoring of groundwater quality. The piezometers should be multiple sampling devices and be installed specifically at sites 7, 9, 12 and 22 (shown in Figure 7 as Waterloo Research Institute sampling points). These sites are close to the perimeter of the landfill where contamination has been confirmed. Details on the design and installation of these piezometers and a sampling protocol are contained in Waterloo Research Institute's final report to the Committee. For the next five years, the analyses of groundwater samples should be carried out twice a year using the best available approach to quantitative analysis of organic compounds, which is currently GC-MS.

D5. CHEMICALS IN LANDFILL GAS AND SURROUNDING NEIGHBOURHOODS

D5.1 Chemicals in Landfill Gas

The chemicals in highest concentrations in the gas were the aromatic hydrocarbons. Chlorinated hydrocarbons (dichloromethane, 1,1-dichloroethane and 1,2-dichloroethene) were also found in appreciable amounts at a number of sites. In general, however, only relatively low concentrations (i.e., low ppm range) of most compounds, including PAHs, were observed in the undiluted landfill gas. This gas is diluted by air by as much as 1,000 times at a distance of only one metre from the gas vents. The landfill gas contains some mutagenic chemicals but not in high concentrations.

D5.2 Chemicals in Neighbourhood Air

Only a few compounds, primarily the aromatic hydrocarbons (benzene, toluene, xylenes) were detected at low ppb levels. There was no clear trend in the concentration of these compounds over time and levels were as high or higher at upwind and control sites as they are downwind from the landfill. These findings show that the contribution of chemicals from the landfill is small compared to the contribution from motor vehicles and other non-landfill sources of air pollution. Concentrations are similar to those observed in other cities.

D5.3 Collecting and Flaring Landfill Gas

D5.3(a) Considerations. Current emissions of target compounds from the landfill are producing ambient air concentrations of these compounds that are not measurably higher than background. On the other hand, there are many unidentified compounds of landfill origin, some of which may be harmful to human health, although on the basis of current evidence this seems unlikely. Furthermore, one cannot ignore the possibility that at some future time emission of toxic substances from the landfill could be much greater than at present and become a hazard to human health. This concern, nevertheless, must be put into perspective. The most toxic compound found in appreciable concentrations at the present time is benzene. The measured levels of one to four parts per billion would need to increase several hundred fold before the currently accepted ambient air quality standard in Ontario of 950 parts per billion would be exceeded.

It should be pointed out that while there is good evidence from modelling studies that on a time-average basis the concentrations of identified compounds are below those considered dangerous to human health, there may occasionally be air currents that could result in contamination plumes in which concentrations are much greater than average.

The health studies (see the following section) have provided evidence that before 1980 (when the landfill was in operation) there was an association between working or living near the landfill and an increase in certain health conditions. While the health conditions appear to relate to past rather than current exposure, the findings point to the need to control emissions.

In addition to these considerations, there is the matter of the unpleasant and sometimes nauseating odour in the neighbourhoods, which is a constant reminder to area residents of their possible exposure to toxic and carcinogenic chemicals. The accelerated pace of residential and commercial development that has been evident recently in close proximity to the landfill further suggests that the magnitude of public concern will increase over time if efforts are not made to address the odour problem. The Committee has concluded that the need to eliminate the odour problem alone provides sufficient reason for burning off the landfill gas. It should also be pointed out that landfill gas is being flared at at least five sites in Ontario for the purpose of controlling odour and methane migration.

D5.3(b) Proposed Gas Collection and Flaring System This work should be implemented in three stages, the first of which would consist of a continuous pumping and flaring test to be carried out for at least one month on three test wells to be installed on the Stone Church Road side of the site. This first stage can be used to evaluate further the byproducts of the gas combustion as well as provide data for designing the permanent installation.

The second stage would involve the construction of a permanent installation along the Stone Church Road side of the landfill. The estimated cost of this second stage was estimated in 1983 to be about $600,000, with an additional annual operation and maintenance cost of approximately $50,000.

The third stage in the installation of a gas control system involves constructing a system on the Red Hill Creek side of the landfill which is estimated to cost aproximately $500,000. This system would also require additional annual operation and maintenance expenditures.

RECOMMENDATION 18: The Committee recommends that an active landfill gas collection and flaring system be installed at the Upper Ottawa Street landfill and that the first phase of this work should begin as soon as possible.

D5.4 Air Monitoring

Until a gas collection and flaring system is constructed at the landfill, an extensive program of air monitoring in neighbourhoods surrounding the site is needed to show whether the toxic or carcinogenic compounds being released in landfill gas continue to be diluted to safe levels offsite.

Once the gas collection and flaring system has been installed, the monitoring program recommended below should be reviewed and modified.

RECOMMENDATION 19: The Committee recommends a monitoring program consisting of a minimum of six air tests annually, each involving the analysis of at least four samples of landfill gas from the existing test well (site 1 in Figure 12 and Appendix 5) and other gas probes or boreholes on the landfill and at least three samples of ambient air from sites upwind and downwind of the landfill and on the site itself. Samples of landfill gas should be collected in air bags, and samples of ambient air by sorbent tubes until better sampling techniques are developed. Samples should be analyzed using the best available methods for quantitative analyses of trace organic compounds, which at the present time is the GC-MS method. The compounds detected in the Committee's work should serve as the target list for these analyses. Analysis should also be capable of detecting 'priority pollutants' not detected in the Committee's work.

RECOMMENDATION 20: The Committee recommends that an air monitoring program be continued until there is evidence that the production of gas within the landfill has declined significantly.

RECOMMENDATION 21: The Committee recommends that the air monitoring data be reviewed by appropriate persons in the city and regional governments, by the Ontario Ministry of the Environment and by at least one external consultant. The results should be made public each year.

D6. THE HEALTH SURVEY OF LANDFILL WORKERS

D6.1 Results

Interviews were completed with 313 landfill workers and control subjects and the following results were obtained.

1) The main conclusion of the workers health survey is that three groups of health problems appear to be associated with working at the landfill: chronic bronchitis, daily cough, combined respiratory problems; certain central nervous system symptoms such as headaches, dizziness, lethargy and balance problems; and mood disorders such as anxiety, depression, trouble sleeping, irritability and restlessness.

2) Also identified were health problems having a weaker association with working at the landfill than the three groups of health problems identified above: difficulty breathing, skin rash, combined skin problems, and muscle weakness in arms and legs.

3) The landfill workers were most likely to have first developed these health problems between 1970 and 1980, which coincides with the periods of increasing and maximum waste disposal at the site.

4) Landfill workers tended to develop these health problems in the first five years after they began to work at the landfill, which implies that if the landfill is the cause of these problems longer term exposure was not required.

5) Most of these health problems that developed after first exposure to the landfill have persisted and remain more prevalent among landfill workers than controls.

6) Analysis of the overall pattern of mortality for 21 landfill workers who died between 1965 and 1983 indicates that there was no significant difference in the mortality risk for landfill workers at the time the study was conducted, although this analysis has limited statistical power.

7) The medical chart abstraction study demonstrated that landfill workers did not over-report their health problems compared to controls.

8) No statistically significant differences were found between landfill workers and the control group for 107 other health problems listed in the questionnaire. These include high blood pressure, stroke, diabetes, gall bladder disease, all of which have no known chemical-related cause, and other problems such as stomach ulcer, gastrointestinal, reproductive, kidney and bladder conditions and diseases of the blood, which can be caused by chemical exposures.

D6.2 Discussion

These findings strongly suggest an association between working at the landfill and certain health problems. The results of the study, however, cannot be used independently to draw conclusions about causation because the strategic objective was to conduct an hypothesis generating study to provide target health problems to be investigated in the residents study. The fact that similar findings were obtained in the residents study supports the view that health problems observed in the landfill workers are related to exposure to landfill chemicals.

In light of this, an important issue is what, if anything, should now be done about workers' health. It is of significance that the identified health problems are not considered to be severe in terms of disability at home or in the workplace. They are common to the general population and are treated routinely by family physicians. None of the findings of the workers health study suggests the occurrence of specific chemically-related diseases that could be detected through biological monitoring or laboratory testing.

One important aspect is that workers may have been exposed to unknown levels of carcinogenic chemicals at the landfill. No increased incidence of cancer was observed in landfill workers but given the long latency period for development of cancer, final conclusions cannot be reached for at least two decades following the period of exposure. Recommendation 22 below pertains to the monitoring of any possible change in cancer risk for landfill workers and area residents.

D7. THE HEALTH SURVEY OF LANDFILL RESIDENTS

D7.1 Study Design

The design of the residents study focused on the associations found in the workers study between certain health conditions and working at or near the landfill. The study encountered two problems that could reduce the strength of its findings: a high refusal rate among the controls (32.2 per cent versus 18.8 per cent for the landfill residents group) and a moderate difference in socioeconomic status between controls and landfill residents (controls have higher incomes, more education and a higher proportion of white collar jobs than landfill residents) although, in retrospect, no better neighbourhood match could be found in Hamilton.

D7.2 Results

Interviews were completed with 1,328 households in the landfill and control neighbourhoods, which involved collecting detailed health histories for 5,118 people.

1) A positive association is indicated between landfill residence and certain respiratory, skin, central nervous system (headaches, dizziness, fatigue) and mood (anxiety, depression, irritability) health problems in adult landfill residents. These

findings are consistent with the workers study. Similar results were also obtained for children living near the landfill, with the difference that respiratory conditions were not statistically significant but red, itchy eyes were.

2) It was observed that adults with longer-term residence in houses located closer to the landfill had a higher incidence of these health problems than did adults living in similar households located farther away from the site. This provides strong evidence in support of an association between the observed health problems and chemical exposure.

3) The response to decoy questions included in the questionnaire provided no evidence that residents living near the landfill developed health conditions that are unrelated to chemical exposure.

4) The assessment of recall bias in the medical chart abstraction study found no evidence from doctors' records that landfill residents were over-reporting or under-reporting their health problems on the questionnaire as compared to the controls.

5) The excess health problems occurring in residents of the landfill area developed while the landfill was open and large amounts of wastes were being deposited. The health conditions reported on the questionnaire as first developing before 1981 have been disappearing at a similar rate for residents and controls. There is no convincing evidence that exposure to the landfill after it was closed and covered in 1980-81 has led to health problems among area residents.

6) No pregnancy problems, including stillbirths, miscarriages, low birth weight or birth defects, were observed in residents living near the landfill as compared to controls. These problems are sensitive indicators that have been found in other studies of landfill populations. It is, therefore, reassuring that these problems were not seen here.

7) There was no evidence of increases in major chronic diseases among residents living near the landfill.

D8. POSSIBLE CAUSES OF IDENTIFIED HEALTH PROBLEMS

While the cause of the observed increased incidence of health conditions appears to be associated with living near the landfill (or working at or near the site), it has not been possible to identify the causative agent or agents. The health problems could be caused either by actual chemical exposure or by a perception that living near the landfill is a health risk. This concern over the potential harmful effects of exposure to the landfill could have given rise to genuine health problems or symptoms of stress.

D8.1 Causation by Chemical Exposure

The results from the residents health study suggest six lines of reasoning that favour chemical exposure as the cause of the observed excess of some health problems in landfill workers and residents:

a) The fact that essentially the same health problems were identified by workers and residents cannot be easily explained by perceptual factors, especially considering the lack of contact between the two groups and the different perceptions of risk expressed by them.

b) The observation that there were more health problems among residents who have lived closer to the landfill for longer periods of time than those who lived farther away, or were resident for a shorter period, seems too coincidental to be explained by the perception of risk by persons living near the landfill.

c) The health problems identified in workers and residents are ones that could have been caused by chemical exposure and are, therefore, biologically plausible. If perception were the cause it is likely that a variety of other health problems not related to chemical exposure would also have been identified.

d) The health conditions observed in workers and residents were not those found in a well-publicized health survey conducted by the Residents Association before the Committee's health surveys were initiated. If the residents had been influenced by their perceptions of exposure, it is likely that there would be some overlap between both sets of findings.

e) The assessment of recall bias in the medical chart abstraction study did not find evidence of over-reporting of health problems on the questionnaire by landfill workers or residents as compared to controls.

f) The health problems that first developed in workers and residents when the landfill was open seem to be disappearing at the same rate as those being experienced by the control groups. In addition, landfill residents do not report disability from respiratory complaints. These findings are not characteristic of learned illness behaviour.

D8.2 Causation by Perception of Chemical Exposure

There are four lines of reasoning, however, that appear to suggest a case for a 'perception of exposure' mechanism:

a) Nuisance odours are still a frequent problem in the area and it is possible that these odours have contributed to an increased level of concern among area residents.

b) The specific health problems found in excess among landfill workers and residents (i.e., respiratory, skin, certain central nervous system, mood) can all be explained by behavioural mechanisms. None uniquely requires chemical exposure or is based on evidence of human tissue damage.

c) Perceptual factors could have been influenced by the unblinded study design (i.e., interviewers knew who were landfill workers and residents and controls and, therefore, could have treated the study groups differently). In addition, the medical chart abstraction study could simply have confirmed that landfill workers and residents sought medical help for perceived problems.

d) Some patterns of health problem reports between former landfill residents (migrators) and current area residents can be more easily explained by perception of exposure to chemicals emitting from the landfill than by exposure itself.

It is the opinion of the Committee that the weight of the evidence is stronger in favour of a chemical exposure cause for the excess health problems identified in both landfill workers and residents.

D9. FOLLOW-UP STUDY

D9.1 Study of Psychosocial Effects

The findings of the health studies provide no basis for assuming that a pattern of continued ill health exists or that the current health status of people living near the landfill could be further defined or explained by a study of psychosocial effects. A second consideration is that the Committee is unable to identify any direct benefits for residents that would result from such a study. It is concluded that there is insufficient justification for recommending that a large-scale psychosocial study be conducted as a followup to the Committee's investigation.

D9.2 Laboratory Tests and Biological Monitoring

There is nothing in the results to indicate that clinical examination, laboratory tests or biological monitoring would be useful in the further examination of the health of the landfill workers or area residents. Of particular importance is the lack of any indication that there is significant current exposure and the failure of the questionnaire survey to identify specific diseases that can be directly related to chemical exposure. Further, it appears that the health problems diagnosable by objective tests that may have existed in the landfill population are disappearing.

D9.3 Population Registry

In view of the fact that the period of the study was too short to detect an increased incidence of cancer and that there is a lack of evidence about whether or not workers and residents were exposed to significant levels of cancer causing chemicals, the Committee recommends the establishment of a registry of landfill workers and residents who were identified for the health surveys. This recommendation in no way suggests that the Committee has any evidence suggesting that workers and residents are more likely than the general population to develop cancer as a result of their working or living near the landfill.

> **RECOMMENDATION 22: The Committee recommends setting up a registry of landfill workers and area residents who were identified for the health surveys for the purpose of following the incidence of cancer in these populations. The registry should be set up under the auspices of the Ontario Cancer Treatment and Research Foundation.**

PART 1

OVERVIEW OF THE PROBLEM

Introduction to the Report

Historical Development

Planning Landfill Investigations: Overview

CHAPTER 1

INTRODUCTION TO THE REPORT

The purpose of this report is to present the findings and recommendations of an investigation of the human health and environmental impacts associated with exposure to the Upper Ottawa Street landfill site.

The Upper Ottawa Street landfill site is located on the east mountain in Hamilton, Ontario. Figure 1 shows the general location of the landfill and Figure 2 shows the areas surrounding it that are referred to in this Report. Upper Ottawa Street and the Quinndale neighbourhood are on the west side. The neighbourhood contains two elementary schools, Blessed Kateri Tekakwitha and Cecil B. Stirling, and houses, within approximately 500 metres of the site. A public works yard is located between the landfill and the houses on Upper Ottawa Street. The landfill is bordered directly on the north side by the Red Hill Creek and houses along Limeridge Road are about 500 metres to the north of the Creek. The railway tracks form the eastern boundary of the site, beside which is located a conservation park area. Albion Falls is within 750 metres of the site to the east. Stone Church Road is along the southern end of the landfill, and a light industrial development is located across the street. A training facility for firefighters is situated on the southwest corner of the site.

Approximately 615 households are located within 500 meters of the landfill, mostly to the west and north of the site. At a distance of 750 metres from the landfill there are an additional 960 households. The residential development on the west side along Upper Ottawa Street is a high density townhouse area with detached single family housing. This housing mix is characteristic of the north side of the landfill as well.

From the early 1950s until it was closed in 1980, the landfill received all types of domestic and commercial waste as well as solid and liquid industrial wastes from the Hamilton region, elsewhere in Ontario and from the United States. What began as a rural quarry dumpsite is now a 30 metre high garbage mound covering about 16 hectares.

Beginning in 1980, the mound was covered by an intermediate layer of solid waste materials supplied by the steel industry, ranging from a depth of up to six metres on the flat top of the landfill to less than one metre on the steep slopes. The cap, which is as deep as one metre in some places on the landfill, is a layer of excavated soil consisting largely of clay. Grass seeding has been fairly successful after several attempts. More recently, tree planting has been undertaken.

Some deep erosion gullies have formed on the sides of the landfill from runoff of surface water and leachate (i.e., the liquid formed by water percolating through garbage). This is of particular concern on the north side of the landfill, which impinges directly on the Red Hill Creek. An erosion wall, approximately three

FIGURE 1: Location of Upper Ottawa Street Landfill Site

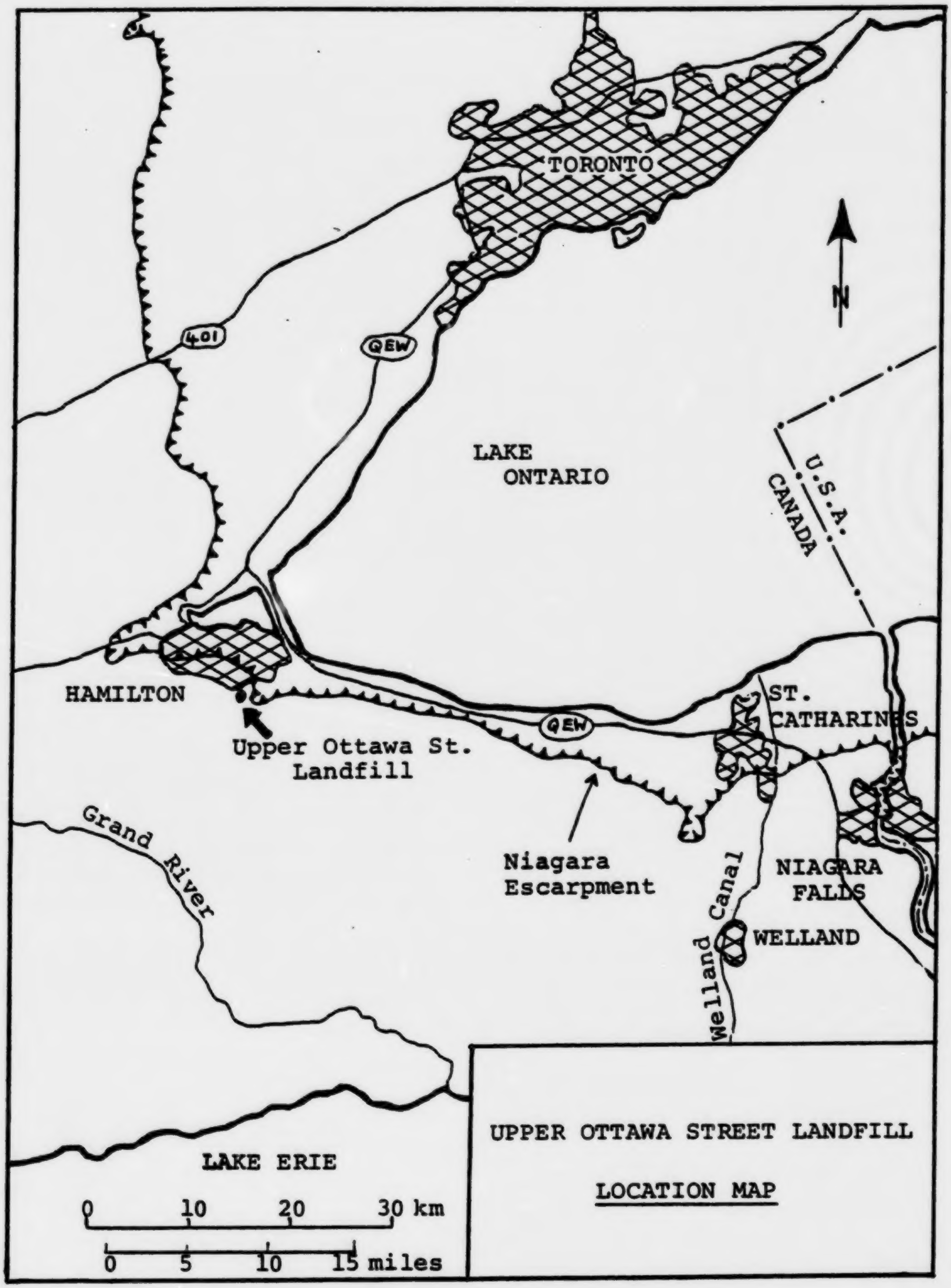
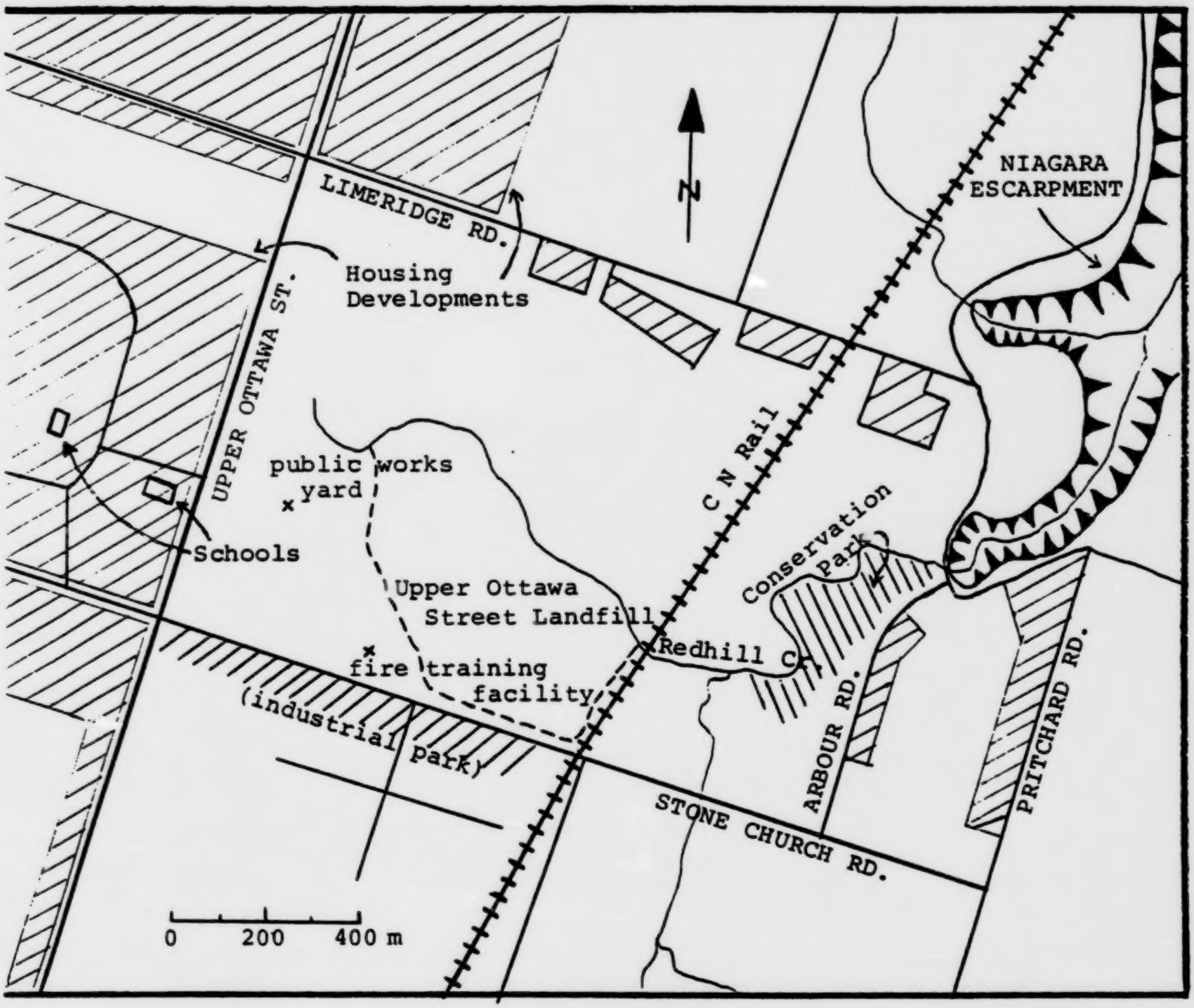

TORONTO
N
401
QEW
LAKE ONTARIO
U.S.A.
CANADA
HAMILTON
Upper Ottawa St. Landfill
QEW
ST. CATHARINES
Niagara Escarpment
Grand River
Welland Canal
NIAGARA FALLS
WELLAND
LAKE ERIE
0 10 20 30 km
0 5 10 15 miles
UPPER OTTAWA STREET LANDFILL
LOCATION MAP

FIGURE 2: Location of Landfill and Surrounding Neighbourhood


N
LIMERIDGE RD.
NIAGARA ESCARPMENT
Housing Developments
UPPER OTTAWA ST.
C N Rail
public works yard
Schools
Conservation Park
Upper Ottawa Street Landfill
Redhill C.
fire training facility
(industrial park)
ARBOUR RD.
PRITCHARD RD.
STONE CHURCH RD.
0
200
400 m

metres high, separates the base of the landfill from the creek. The site was not completely fenced until after the landfill was closed, but the north side of the landfill remains unfenced on the Red Hill Creek side.

A leachate collection system of pipes was installed around three sides of the landfill in 1981-82. The leachate flows by gravity or is pumped upgradient into a sanitary sewer, which goes to the city sewage treatment plant. A row of 18 gas vents extends across the south side of the landfill to facilitate the passive emission of methane gas from what appears to be the most active gas generating area of the site.

The landfill sits on fractured bedrock in contact with groundwater, but the aquifer is not used as the local water supply. It has been established that the prevailing wind direction is from the west towards the east away from nearby residential areas, but there are variations in this pattern.

In October of 1980, the Regional Municipality of Hamilton-Wentworth closed the Upper Ottawa Street landfill because a new alternative facility was developed. There was also public concern about possible exposure to toxic chemicals that might be buried there. The Upper Ottawa Street Residents Association was effective in expressing the concern of its members about possible health hazards associated with living near the landfill. At the same time, the Region requested the Ontario Government's Ministry of Health to carry out a health study, and a Study Committee was appointed to conduct this work. The Committee began to plan its investigation in April of 1981.

The Committee's terms of reference are:

a) to investigate the chemical nature of the materials deposited in the landfill site, changes in the materials in that environment, and the migration of chemicals away from the area;

b) to study the possible existence at or about the landfill site of a hazard to human health; and

c) to consider such other matters brought out in the course of the Committee's activities that are relevant to the terms of reference.

It was stressed by the Ministry of Health that the investigation was the first of its kind in Ontario and would need to be conducted in a thorough and comprehensive way so that it would be useful as a prototype with application to problems at other landfills in the future.

The Ministry of Health also provided separate funding to the Upper Ottawa Street Residents Association so that the residents could select their own technical consultant who, on their behalf, would provide advice to and review the work of the Committee. The Residents association selected Dr. Steven Safe, a toxicologist formerly with the University of Guelph, Ontario and now at Texas A & M University.

Part 1 of this Report comprises this Introduction, a discussion in Chapter 2 of the specific characteristics and background of the Upper Ottawa Street landfill and, in Chapter 3, an outline of the research plan and objectives of the Study Committee in the context of the state of the research on chemical waste disposal sites in Canada and the United States.

Part 2 of this Report consists of six chapters, which present the results of the analytical work required to identify potentially toxic substances contained within and, more importantly, migrating from the landfill. The results of analyses of core samples from boreholes penetrating the landfill itself and analyses of materials used to cover the site are discussed in Chapter 4. The results of extensive organic analyses of leachate, sediments and the Red Hill Creek as well as separate analytical findings of other groups, primarily the Ontario Ministry of the Environment, are discussed in Chapter 5.

The findings of a two year hydrogeological investigation to determine the direction and rate of groundwater flow and the chemical nature of the groundwater plume are reported in separate chapters: Chapter 6 discusses the factors affecting groundwater flow, and Chapter 7 presents the results of groundwater chemistry analyses.

A primary concern of the Committee was with air contamination since air is the most likely potential route of chemical exposure for area residents. The results of air testing programs conducted for the Committee, which include analyses of landfill gas and of air samples from other onsite and offsite locations, as well as the findings of gas collection and flaring experiments, are presented in Chapter 8. Chapter 9 provides an overview of the toxicological findings of chemicals detected in the landfill and the implications for human health.

The most important aspect of the Committee's investigation was concern for public health and any possible health hazards that might be associated with exposure to chemicals in the landfill. This work is presented in Part 3 of this Report. Chapter 10 provides an introduction to the health studies reported in subsequent chapters. Chapter 11 presents a study of the health of landfill workers. This is followed, in Chapter 12, with the results of a major study of the health of residents living in proximity to the landfill. Both of these studies consisted of health survey questionnaires administered by trained interviewers, the use of control populations for comparing the health of landfill workers and residents to similar groups of people working and living elsewhere in Hamilton not near a landfill, and medical chart abstraction studies which involved examining the medical charts kept by the family doctors of study participants.

The conclusions and recommendations reached by the Committee with respect to all aspects of its investigation are discussed in Part 4, Chapter 13, which concludes the Report.

CHAPTER 2

THE HISTORICAL DEVELOPMENT OF THE UPPER OTTAWA STREET LANDFILL SITE

TABLE OF CONTENTS

Page

A. INTRODUCTION 10

B. EXPANSION OF LANDFILLING OPERATIONS 10

C. OPERATIONAL ASPECTS 11

D. OPEN BURNING 13

E. POLLUTION OF THE RED HILL CREEK 14

F. LIQUID INDUSTRIAL WASTE 16

G. SITE CLOSURE 17

H. RESIDENTIAL DEVELOPMENT IN THE VICINITY OF THE LANDFILL 19

Figures Page

3 Historical Development of the Site 1954 - 1978 12

4 Location of Households by Distance From the Landfill 21

5 Growth of Population in the Vicinity of the Landfill 22

References 23

A. INTRODUCTION

Dumping at what is now known as the Upper Ottawa Street landfill site is believed to have started in 1952 in a quarry on land that was originally a farm. The lack of records about the wastes that were actually dumped in the site makes information about its historical development particularly important. This "mountain dump" was annexed to the City of Hamilton in 1960, and a certificate of approval for a sanitary waste disposal site was received from the Province in 1971. In 1975, the City transferred ownership of the Upper Ottawa Street landfill to the Region of Hamilton-Wentworth, but plans are now underway for the Region to return ownership to the City of Hamilton.

Problems have always been associated with landfilling operations at the Upper Ottawa Street site, a situation the Ministry of the Environment attributed to the lack of an operational plan until the later years of its operation. These problems were described as "indiscriminant dumping of garbage, steep slopes around the perimeter of the landfill, and refuse and debris in creeks and the surrounding property."(1)

In 1977, the Region entered into an agreement with a waste management company to allow the construction and operation of a solidification/fixation plant for the processing of inorganic wastes at the landfill. The Ministry of the Environment imposed conditions on this agreement and required its renewal every six months.

The solidification/fixation operation attracted large volumes of liquid industrial waste to the site. This situation raised alarm among area residents, who organized a protest lobby that was effective in stopping the onsite burning of wastes in 1978; stopping liquid industrial waste disposal in January of 1980; closing the solidification plant in April of 1980; and the final closure of the landfill in October of 1980.

This chapter will discuss the historical development of the landfill from a rural dumpsite in the 1950s to one of the largest sites for industrial waste disposal in Ontario. Other aspects of the landfill's operations that will provide background information relevant to the problems of chemical migration and exposure, and environmental and health impacts will also be presented.

B. EXPANSION OF LANDFILLING OPERATIONS

All available stereoscopic aerial photographs were obtained from the Ontario Ministry of Natural Resources for the purpose of interpreting the manner in which the use of the site evolved.

While landfilling may have begun a few years earlier, aerial photographs taken in 1954 were the first to show landfilling at the site. This was restricted to a small area on the western side of the site, shown as area 1 in Figure 3.

Most of the expansion of the landfill took place between 1954 and 1972. Part of the expansion was accomplished by diverting the Red Hill Creek northward before filling in the area that previously served as the flood plain for Red Hill Creek. By 1972, landfilling was essentially completed in the area designated as area 2 in Figure 3.

The 1972 photographs also show that landfilling was in progress adjacent to the railroad tracks along the east side of the landfill as shown in area 3 of Figure 3, and that landfilling had begun along the southern part of the site (area 4). From the photographs it appears likely that the surface soils in this area were excavated prior to landfilling. The area designated in Figure 3 as being disturbed in 1972 probably contained shallow deposits of solid wastes.

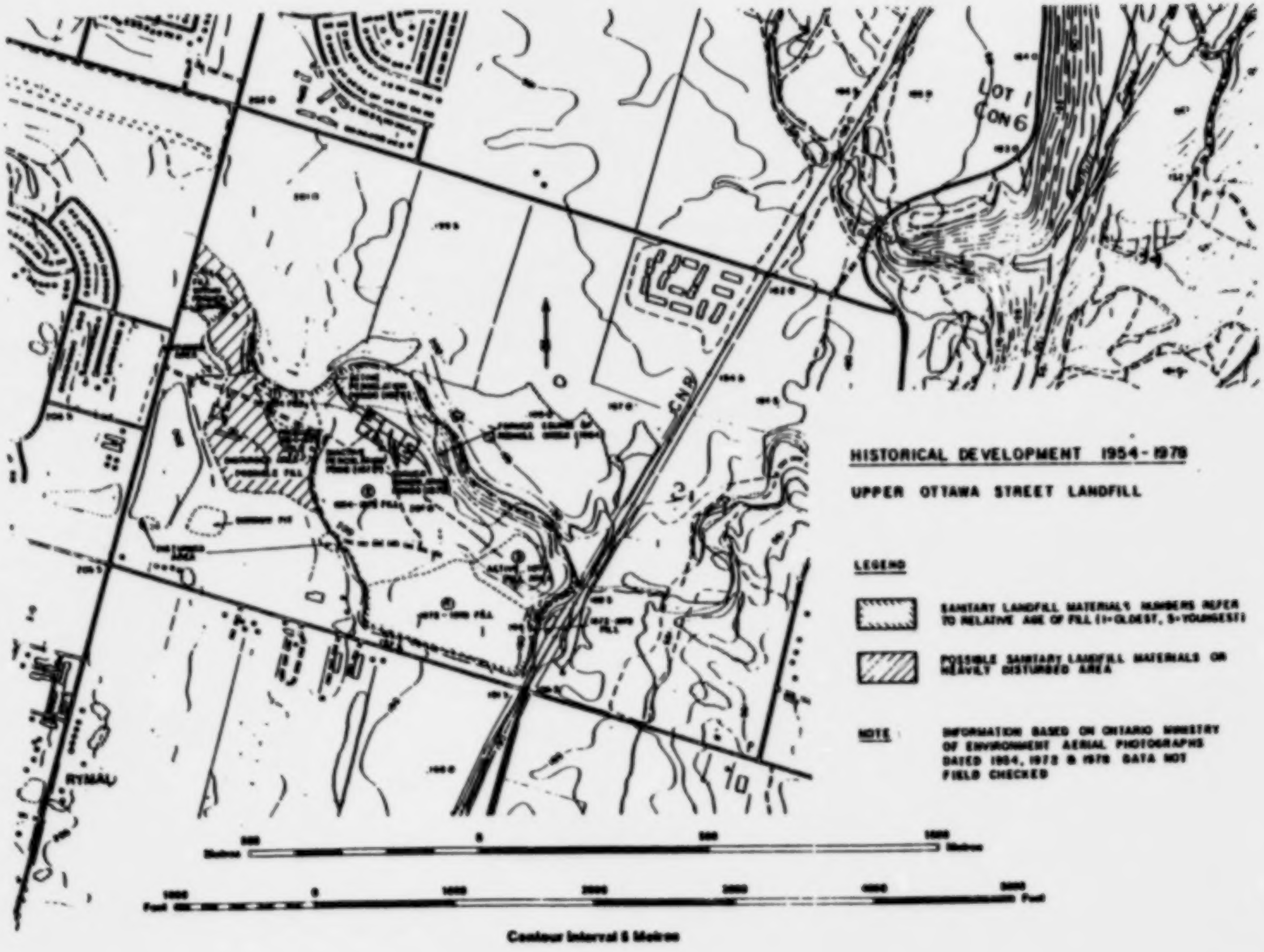
Little lateral expansion of the landfill occurred between 1972 and 1978. Some new filling occurred along the eastern part of the site, shown as area 5 in Figure 3, but most of the landfilling involved topping up of areas 3 and 4. The 1978 aerial photographs show some lagoons on the west end of the landfill that were part of the onsite solidification/fixation plant. The two northwestern ponds contained liquids in 1978. The southwestern ponds did not contain liquids in 1978, but they appear to have been used for the disposal of liquid waste. The other ponds that are evident on the 1978 photographs are indistinct in outline and appear to have been used prior to 1978.

C. OPERATIONAL ASPECTS

The Upper Ottawa Street landfill was open seven days a week, and commercial dumping privileges were supposed to be available only to contractors hauling refuse within the region. An attendant, who was stationed in a guard hut at the main entrance, was assigned to direct all waste to the working face of the site, except for a separate area for the disposal of wood. The city began charging for use of the site in 1965.

In general, the landfill received all forms of solid and liquid residential and industrial wastes. In order to determine the total tonnage of wastes entering the landfill, a 12 metre platform scale was installed in 1977 and over a four month period all vehicles were weighed as they entered the site. It was estimated that 218,659 vehicles (primarily trucks) hauled 881,776 tons to the landfill that year. The heavy traffic flow was particularly noticeable on Upper Ottawa Street and attempts were made at various times to redirect truck traffic and to ensure that the truckloads of wastes were covered.

FIGURE 3: Historical Development


HISTORICAL DEVELOPMENT 1954-1978
UPPER OTTAWA STREET LANDFILL
LEGEND
SANITARY LANDFILL MATERIALS: NUMBERS REFER TO RELATIVE AGE OF FILL (1=OLDEST, 5=YOUNGEST)
POSSIBLE SANITARY LANDFILL MATERIALS OR HEAVILY DISTURBED AREA
NOTE:
INFORMATION BASED ON ONTARIO MINISTRY OF ENVIRONMENT AERIAL PHOTOGRAPHS DATED 1954, 1972 & 1978 DATA NOT FIELD CHECKED
LOT 1
CON 6
CNR
RYMAL
500
0
500
1000
Metres
1000
0
1000
2000
3000
4000
5000
Feet
Contour Interval 5 Metres

The progressive ramp method of landfilling was employed during the 1970s. This involved spreading and compacting solid waste on the working face of the landfill. Two compacters (one 27,000 kg, the other 18,000 kg) and one 13,600 kg bulldozer were used for compacting and covering the wastes beginning in 1974. By 1978, the working face size was approximately 2.4 metres high by 15.2 metres long. At the end of the working day the garbage on the working slope was compacted, and the following morning the top of the slope was covered with 15 cm of cover material. This material consisted mainly of industrial steel wastes, but other solid industrial byproducts and excavation materials also were used for this purpose.

Residents and workers informed the Committee that the landfill was an extremely dusty site. This would have been particularly noticeable during the closure period from November 1980 to June 1981, when it was estimated that over 200 truckloads of steel industry wastes were transported daily to the landfill. Another source of dust was the access roads on the site. Records show that the access roads were oiled regularly once a week until the site closed. Landfill workers contend that liquid wastes were used for dust control.

The permanent workforce employed by the City or Region at any one time on the landfill itself was small. In 1978, landfill personnel consisted of six machine operators, two attendants, one ticket collector and one foreman. A large quonset building used for sheltering workers and storing equipment was located on the landfill inside the main entrance on the west side of the site.

Beginning in 1955, the municipality granted licenses to allow controlled salvaging. Salvage pickers were required to renew their licenses monthly. In 1966, for example, 16 salvage pickers were licensed. By 1978, 11 salvage pickers remained on the landfill, and the Region decided not to license new applicants. Efforts to locate former salvage pickers for the Committee's health studies suggest that the number of persons engaged in salvaging over the 23 year period was likely less than 20.

D. OPEN BURNING

Before the solidification/fixation plant was built on the landfill in 1977, the greatest source of public complaint was the weekly burning of wood and wastes in open fires. The open fires were set alternately on the southeast and northeast corners of the site.

The practice of open fires at the site appears to have begun in response to a consultant's report in 1960.(2) The consultant recommended burning timber and brush that had accumulated on the mountain dump because disposal of wood leads to cavities in the fill and later subsidence of the landfill as the wood decomposes. Another consultant's report in 1967 estimated that the mountain dump was receiving an average of 150 tons of wood daily.(3) The report pointed out that new standards proposed by the provincial Department of Health would prohibit open burning, and the consultants recommended the construction of an incinerator.

The practice at the site was to carry out the burnings early on Sunday mornings to minimize complaints. In 1965 the municipal laboratories investigated the effects of the fires at the mountain dump and reported that the dustfall at a house on the east side of the landfill amounted to 25 tons per square kilometre per month, which was about four times the average rate observed elsewhere on the Hamilton mountain.(4) In 1967, the East Mountain Homeowners Association complained to the provincial government that "the large, open fires resulted in charred and partially burnt garbage blowing as far as two miles from the site."(5)

Uncontrolled fires on the landfill were not uncommon and were caused by the open burning of wood and garbage. In 1965, newspaper reports described a fire that had "raged out of control" and made it impossible for neighbouring residents to leave their houses because of smoke and foul odours.(6) In 1973 a similar episode that lasted for several days was reported.(7)

In 1977, the Ontario Ministry of the Environment notified the Region of guidelines for open burning: only clean wood was to be burned; burning was not permitted if wind speed exceeded 15 knots or when it rained; and fires were to be controlled and attended at all times.

The Upper Ottawa Street Residents Association was initially formed in 1978 to combat the open fires and the dumping of liquid industrial waste. The fires were described to be "like a volcano erupting across the street" and "the flames were about sixty feet (18.3 metres) in the air."(8)

The residents were convinced that the "sludge" product resulting from the solidification/fixation plant was combustible and was mixed with garbage for the burning. The Region claimed that attempts were being made to segregate wood from other wastes and, by the mid-1970s, the wood burning area was away from the landfilling operation, in the southeast corner of the site.

In October 1978 the Residents Association held a public meeting calling for a ban on all burning. One month later, the Region stopped the practice of the deliberate burning of wood at the landfill.

E. POLLUTION OF THE RED HILL CREEK

Landfill contamination of the Red Hill Creek has been recognized as a problem for many years.

A 1965 report by the Ontario Water Resources Commission concluded that the "gross pollution of the Red Hill Creek appears to have been caused by the unsatisfactory operation of the dump."(9) At that time the landfill adjoined the creek bank for approximately 365 metres, and garbage, burned material and leachate were entering the creek and discolouring the water. The Commission recommended that steps be taken immediately to stop the use of those portions of the landfill located near the creek and to protect the creek from continuing pollution by diverting surface drainage into a ditch. It was suggested that relocating the creek bed or removing portions of the landfill were the only means of permanent rehabilitation.

An inspection during the same period by Hamilton's Medical Officer of Health also led to his recommendation to separate the garbage from the creek. He observed that the Red Hill Creek was dammed on the landfill property, causing the creek to become almost stagnant before reaching Albion Falls.(10)

A 1968 Hamilton Region Conservation report identified the landfill as a serious pollution threat to the Red Hill Creek and recommended that seepage and surface water from the landfill be collected and pumped into a proposed sanitary sewer system.(11) The report also noted that the number of fish and other aquatic species diminished rapidly in the part of the creek that bordered the landfill.

The Hamilton Region Conservation Authority subsequently commissioned a study of Red Hill Creek with a view to developing the Mount Albion conservation area situated upstream of Albion Falls.(12) The Red Hill Creek Water Management Study was completed in 1975, and it pointed to the direct discharge of drainage and leachate from the Upper Ottawa Street landfill as the most obvious source of pollution. Numerous measures to correct the problems at the landfill were recommended. These included the installation of a system that would pipe leachate from the north and south ends of the landfill and collect it in a pond in the low-lying east side of the site beside the railway tracks. It was anticipated that a sanitary sewer would be constructed in 1976 and that the pond could then be connected to it. Additional recommendations dealt with site operations, including a statement of support to continue the temporary ban of dumping of all liquid wastes and sewage, which was then in effect.

In 1978, the Ontario Ministry of the Environment reported its findings on the effects of the landfill on Red Hill Creek.(13) The Ministry analyzed samples of leachate, and water from the creek, primarily for general water quality parameters and heavy metals (see page 72 in Chapter 5 of this report). It was concluded that landfill pollution of the creek was limited mainly to the organic decomposition of domestic waste, that metals did not appear to be a problem and that the source of severe bacterial contamination was upstream of the landfill. Ministry officials were of the opinion that the explanation for these results was the low volume of leachate reaching Red Hill Creek compared to streamflow, and the resultant dilution of the wastes. The report, however, identified the potential that existed for increased leachate generation at the site because no effort was being made to prevent the infiltration of precipitation into the garbage mound. The report recommended the application of a clay cover, vegetation and stabilization of the north side of the landfill above Red Hill Creek.

When the Committee first inspected the site in the spring of 1981, the landfill had been closed for seven months and a final cover had been installed. The Committee observed that leachate springs had broken out half way up the steep slopes of the landfill. This pattern was interpreted to mark the height at which the water table had mounded within the site. Leachate springs and deep erosion channels were particularly evident on the north side where the landfill intersected Red Hill Creek. The Committee also observed the stagnant, black pool of leachate, referred to as the "blackhole" by residents, on the east side of the site. Drainage from the blackhole was entering the creek.

In the following year, the blackhole was emptied and a leachate collection system was installed. A cement "apron" or retaining wall was built to prevent the erosion of the north slope of the landfill into the creek. The site closure procedures and continuing maintenance problems are discussed in the following sections of this chapter.

F. LIQUID INDUSTRIAL WASTE

On the original 1971 application for a Certificate of Approval for the Upper Ottawa Street landfill, the City of Hamilton stated that only one per cent of the total amount of waste would be liquid industrial. By 1975, it was estimated that the landfill was receiving approximately 2.5 million litres annually of liquid waste, primarily from the local steel industries, but because of the lack of records it is not possible to know what percentage this estimate is of the total amount of wastes.

Liquid wastes appear to have been disposed of either by being poured over solid garbage on the working face of the landfill or by being buried in containers. With respect to the latter, some reports suggest that barrels were stacked in piles and covered carefully. Others claim that most barrels were crushed by bulldozers on the working face of the dump.

The volume of liquid wastes transported to the site changed dramatically in 1976-1977. The estimate of more than 22 million litres of liquid wastes deposited at the landfill in 1977 was ten times the amount estimated to have entered the site two years earlier.(14)

A provisional certificate of approval was issued by the Ontario Ministry of the Environment for the operation of a solidification/fixation plant at the Upper Ottawa Street landfill in 1976. It was required that the certificate be renewed every six months, and among the conditions imposed was a stipulation that the wastes processed by solidification be only those generated within the Hamilton region. The Ministry of the Environment approved the solidification operation as an experimental process. Consequently, the Upper Ottawa Street landfill received large volumes of liquid wastes required for testing the solidification process. These wastes were supposed to contain only metals for which the solidification process was designed to treat.

The solidification operation involved a workforce of three persons. The operation employed a proprietary process that claimed to transform inorganic liquid wastes into solid form. These liquid wastes (primarily sludges containing heavy metals) were stored in three open lagoons, each with a capacity of 246,000 litres. Fixation took place in a mixing tank, and the resulting product (supposedly inert material) was landfilled. The solidification operation was owned by a large waste management company with a number of operations throughout the Hamilton area. This company hauled wastes intended for direct disposal on the working face of the landfill, as well as wastes to the solidification plant.

In the fall of 1978, waste haulers, residents and opposition politicians made allegations that illegal activities surrounded the operation of the landfill. These allegations included claims that toxic wastes were smuggled into the site, that employees were bribed by waste hauling companies, that waste haulers had illegally obtained keys to the dump, and that there was a leaking solidification tank called the "magic box."(15) These allegations led to an audit of the solidification operation by the Ministry of the Environment. The audit covered a three month period and revealed that approximately 1.9 million litres of liquid waste could not be accounted for. Subsequently, the Ministry laid charges against the company for giving fraudulent information on waybills.

During the audit it was also discovered that the solidification business processed wastes from outside the Region. It has been estimated that up to 25 per cent of the wastes treated by solidification were transported from other locations in Ontario.(16) The audit report indicates that another 25 per cent of the wastes originated with the parent company, which received more than one-third of its wastes from the United States, and that six per cent was from unknown sources. Therefore, it is likely that the solidification plant also processed wastes from the United States.

G. SITE CLOSURE

By the time the Upper Ottawa Street landfill was closed in 1980, it had reached and perhaps even exceeded its capacity. Consultant reports commissioned by the city during the 1960s predicted that the landfill would be filled to capacity no later than 1975. The Ontario Ministry of the Environment recommended the closure of the site during the late 1970s in an inspection report.

During the 1970s other landfills in Hamilton and outside of the Region had reached capacity and had begun to close. This situation, combined with the fact that the Region had been searching for an alternative landfill site since 1972, prolonged the use of the Upper Ottawa Street site. The new Glanbrook landfill was opened in October 1980. Since the closing of the Upper Ottawa Street landfill site, there has been no liquid waste disposal facility operating in the Hamilton-Wentworth Region.

The Regional Department of Engineering commissioned Gartner Lee Associates Limited, consulting engineers and hydrogeologists, to conduct a hydrogeological study and to make recommendations with respect to closure and rehabilitation measures for the Upper Ottawa Street landfill site. On the basis of the consultant's findings, the Regional Engineering Department recommended an \$800,000 spending program in the fall of 1980. By 1985, the total costs of closing the landfill had risen to \$1.2 million.

Under Ontario's Environmental Protection Act, the Region was required to submit closure plans to the Ministry of the Environment for approval.

The closure procedures have consisted of five components: slope stabilization, cover and hydroseeding of grass; construction of a retaining wall on the north slope; installation of a leachate collection system; installation of methane gas vents; and provisions for monitoring of surface and groundwaters and gas migration.

At the beginning of the closure work, the sloped portion of the Upper Ottawa Street landfill was estimated to be in the order of 167,000 square metres. The first problem, therefore, was to stabilize the steep slopes of the landfill and prevent the erosion of cover materials.

The Region addressed these problems by applying in excess of two million tons of steel industry wastes as an intermediate cover on the slopes and top of the landfill. A thin top layer material consisting largely of clay excavated from a nearby construction project, was applied as a top cover or cap on the site. The depth of the cover materials appears to exceed the guidelines of a minimum of 60-100 cm of compacted cover suggested by the Ministry of the Environment.*

Of greater concern than the thickness of the cover is its permeability. The purpose of a cover is to prevent, or to minimize, the infiltration of water into the landfill and thus to reduce future contamination of groundwater by leachate. Tests carried out on the steel wastes and clay cap suggest that these materials may have satisfactory impermeability if erosion is prevented.**

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* Excavation of two holes on top of the landfill by the Region and the Ministry of the Environment indicate that the depth of the steel wastes ranges from 243 cm to 274 cm and the depth of clay from 30 to 53 cm. The Committee also had five holes bored at various locations on the landfill and found the depth of the clay cap to vary from less than 30 to 91 cm.

** In tests conducted for the Region, Trow Limited found the coefficients of permeability of the steel wastes to range from 1×10^{-4} to 1×10^{-6} cm/second and of the local clays to be in the order of 1×10^{-6} to 1×10^{-8} cm/second.

The growth of vegetation is considered a critical aspect of landfill covers because vegetation acts as a barrier to erosion and promotes evapotranspiration.(17) The process of hydroseeding the Upper Ottawa Street site involved spraying a liquid mixture of fertilizer and grass seed directly on the landfill cover. Several applications were required and in the summer of 1985 it appeared that sufficient vegetation had taken root. Also in 1985, a further vegetation program was undertaken involving the planting of twenty five thousand seedling trees, including alder, lilac, sumac and Russian olive.

A concrete wall approximately eight metres high (of which two metres is below the surface) and 675 metres long was constructed on the north slope of the landfill to prevent erosion of the landfill along the Red Hill Creek. The concrete was installed in "envelopes" of fabric (i.e., fabriform erosion control mats) and while it has buckled in places in response to the subsidence of the north slope, it has not broken apart. If another purpose of the retaining wall was to separate the Red Hill Creek from the landfill it has been unsuccessful because leachate springs can be observed flowing down the concrete apron into the creek, and presumably leachate is also flowing behind the wall and into the creek. Deep erosion channels can be observed extending down the north slope above the concrete wall. Evidence of the landfill slope eroding beneath the wall can be observed in some places.

A system of pipes was installed around the west, south and east sides of the landfill to collect leachate. On the south slope of the landfill there is an additional series of gravel troughs known as "french drains", beneath the cover, whose purpose is to intercept the leachate springs commonly found on this slope. The leachate then flows by gravity or is pumped into a leachate collection manhole, which also collects surface runoff. The manhole empties into a sanitary sewer, which leads to Hamilton's sewage treatment plant. At the request of the Committee, the Region installed an elapsed time meter on the well pump in order to provide information on the volume of leachate being transported in one section of the leachate collection system. The installation of the leachate collection system has reduced but not eliminated the occurrence of leachate springs, particularly on the south slope of the site.

A system for controlling methane through passive gas venting consists of a row of 17 "goose neck" vents extending along the entire width of the south slope of the landfill. The vents are installed to depths of approximately one metre beneath the surface. Most of the goose neck vents are attached to the perforated drains of the leachate collection system, a linkage that may restrict the emission of methane if a large volume of leachate is moving through the collection pipes. Odours coming from the landfill are particularly strong on the south slope.

H. RESIDENTIAL DEVELOPMENT IN THE VICINITY OF THE LANDFILL

When dumping began in the mid-1950s, the site was located in a sparsely populated rural area.

The map in Figure 4 shows the location of the landfill site in the Trenholme district. The nearest adjoining districts are those of Quinndale to the west and Rymal to the south of the site. In 1981, the last year in which the landfill was in operation, there were households located in these areas within 500 metres of the landfill, primarily on the west side of Upper Ottawa Street, between Stone Church Road and Limeridge Road, and on the south side of Limeridge Road between Upper Ottawa Street and Mountain Brow Boulevard. If the distance from the landfill is extended to between 750 metres and 1,000 metres, households from the districts of Templemead, Berrisfield, Lisgar, Albion Falls and North Hannon are also included.

From the population statistics shown in Figure 5, the predominant feature is a sudden, large population increase from 1974 to 1976, as a result of the completion of construction of town houses and other housing subdivisions. At the same time population in the Rymal and North Hannon districts has been declining. The former has been developed for light industrial use while the latter district remains essentially rural.

FIGURE 4: Location of Households by Distance from the Landfill

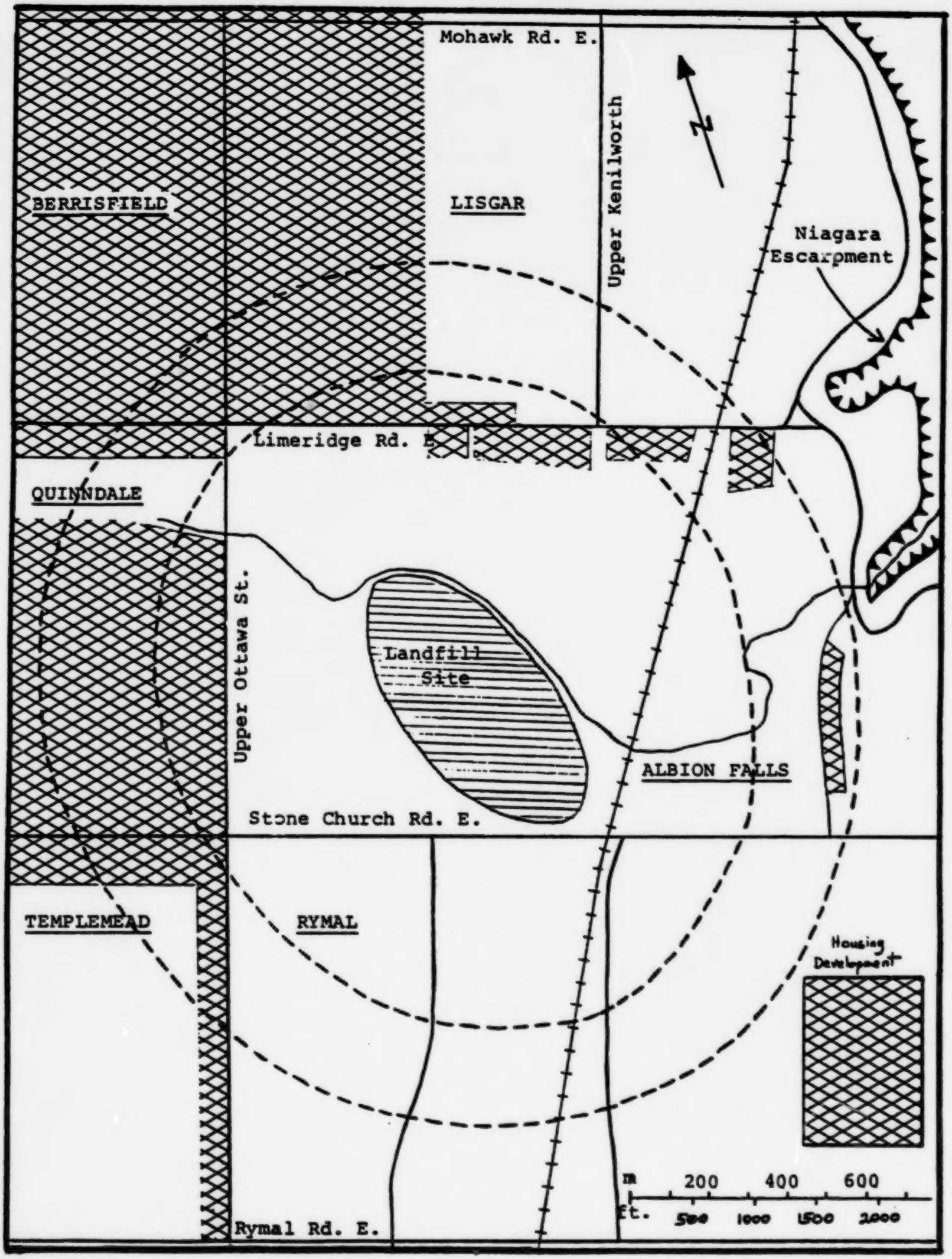
Mohawk Rd. E.
N
BERRISFIELD
LISGAR
Upper Kenilworth
Niagara Escarpment
Limeridge Rd. E
QUINNDALE
Upper Ottawa St.
Landfill Site
ALBION FALLS
Stone Church Rd. E.
TEMPLEMEAD
RYMAL
Housing Development
m 200 400 600
ft. 500 1000 1500 2000
Rymal Rd. E.

FIGURE 5: Growth of Population in the Vicinity of the Landfill

	Berrisfield	Quinndale	Templemead	Lisgar	Rymal	Trenholme	Albion Falls	North Hannon
1969:	2037	124	185	778	181	14	---	--
1971:	2041	128	190	875	182	20	---	--
1973:	3247	99	163	1509	95	15	167	96
1974:	3396	645	148	1884	76	14	156	96
1976:	3653	1533	761	2044	56	392	115	85
1978:	3861	2799	956	2458	45	511	233	78
1979:	3967	2800	1040	2535	29	541	280	88
1980:	4106	3013	1083	2722	12	585	294	69
1982:	4238	3585	1093	3078	5	656	327	77

References

1. Ontario, Ministry of the Environment, Inspection Report on the Upper Ottawa Street Landfill, Region of Hamilton-Wentworth, undated -- 1978 or 1979, p. 7.

2. Canadian-British Engineering Consultants, Report on Refuse Collection and Disposal, prepared for the City of Hamilton, August 1960, pp. 97-8.

3. Gordon L. Sutin & Associates, Report on Refuse Collection and Disposal, prepared for the City of Hamilton, 1967, IV - A - 4.

4. Hamilton-Wentworth Regional Municipal Laboratories, correspondence to Mr. J. Cooke, Hamilton, December 1965.

5. East Mountain Homeowners' Association (Hamilton), correspondence with the Attorney General of Ontario, Toronto, October 4, 1966.

6. "Dump Odours May Start March on City Hall," The Hamilton Spectator, August 19, 1965.

7. "Garbage Smoke Belches Over East City," The Spectator, Hamilton, August 8, 1973.

8. Betty Burcher, "No Love Canal Here," Healthsharing, Winter 1980, pp. 7-10.

9. Ontario, Water Resources Commission, a report re. Municipal Refuse Disposal Site (Mount Albion), submitted to the City of Hamilton, July 23, 1965.

10. Ontario, Medical Officer of Health, correspondence with Commissioner of Streets and Sanitation for the City of Hamilton, June 16, 1965.

11. Ontario, Department of Energy and Resources Management, Conservation Authorities Branch, Hamilton Region Conservation Report, 1968, pp. 28-9, 34.

12. Dillon Consulting Engineers & Planners, Redhill Creek Watershed Management Study, prepared for the Hamilton Region Conservation Authority, June, 1975.

13. Ontario, Ministry of the Environment, The Effects of the Upper Ottawa Street Landfill on Redhill Creek, November, 1978.

14. Ontario, Ministry of the Environment, Inspection Report on the Upper Ottawa Street Landfill, Region of Hamilton-Wentworth, undated - 1978 or 1979.

15. "I sent drums of poison sludge to landfill site," The Sunday Star, Toronto, October 5, 1980.

16. Ontario, Ministry of the Environment, Status Report on an Industrial Liquid Waste Audit in Hamilton-Wentworth, 1978.

17. R.J. Lutton, Evaluating Cover Systems for Solid and Hazardous Wastes, U.S. Environmental Protection Agency: Municipal Environmental Research Laboratory, Office of Research and Development, September 1980.

CHAPTER 3

PLANNING LANDFILL INVESTIGATIONS: AN OVERVIEW OF GENERAL CONSIDERATIONS AND THE APPROACH USED AT THE UPPER OTTAWA STREET SITE

TABLE OF CONTENTS

Page

A. INTRODUCTION 28

B. CURRENT SITUATION IN NORTH AMERICA 28

C. LANDFILL SITE CHARACTERISTICS 29

D. ANALYTICAL TECHNIQUES 30

E. TOXICOLOGICAL ASPECTS 32

F. ROUTES OF TRANSPORT AND EXPOSURE 33

  F1. CHEMICAL CHARACTERISTICS AND PROCESSES 33

  F2. GROUNDWATER MIGRATION 33

  F3. SURFACE WATERS 34

  F4. AIR 35

  F5. FOOD 35

G. HEALTH STUDIES 36

  G1. EPIDEMIOLOGY 36

    G1.1 Study Designs 36
    G1.2 Problems Associated with Landfill Epidemiology Studies 37

  G2. CLINICAL AND LABORATORY TESTS 37

H. RISK ASSESSMENT 38

I. PUBLIC REACTION AND PARTICIPATION 39

Page

J. STUDY PLAN FOR THE INVESTIGATION OF THE UPPER OTTAWA STREET LANDFILL SITE 40

J1. INTRODUCTION 40

J2. CHEMICAL CONTENT OF THE LANDFILL 41

J3. CHEMICAL ANALYSES 41

J3.1 Air 41
J3.2 Leachate and Surface Water 42
J3.3 Mutagenicity Testing 42
J3.4 Groundwater 42

J4. HEALTH STUDIES 43

J4.1 Toxicological Work 43
J4.2 Designing Health Studies of Workers and Residents 44
J4.3 Clinical Studies and Laboratory Tests 44
J4.4 Risk Assessment 45

J5. MISCELLANEOUS STUDIES 45

References 46

Appendix 1
Miscellaneous Studies

A. INTRODUCTION

As a general statement, before undertaking an investigation of health effects associated with any landfill site, information is required on the physical setting and history of the landfill, including, if possible, the quantity and chemical nature of wastes deposited at the site, the identification and measurement of chemical emissions and the assessment of their toxicity, and the pathways of chemical migration and exposure.(1,2,3) On the basis of this information, health studies which may include clinical evaluations and/or epidemiological surveys of the exposed population are then designed. In certain situations it may be possible to conduct risk assessment studies using mathematical techniques to estimate the level of risk for the exposed population.

When the Committee began its investigation of the Upper Ottawa Street landfill in the spring of 1981, landfill operations had ended in the previous year. People were not in direct continuous contact with the landfill and the available analytical findings suggested that only very low concentrations of chemicals were migrating from the site. Since the situation did not appear to be a public health emergency, the Committee was able to plan a long-term study that involved, sequentially, a concerted effort to determine from available records and other sources information on wastes buried in the landfill, chemical analyses of the landfill itself, liquid and gaseous emissions, the ambient environment in the vicinity of the site and, finally, epidemiological studies of the health of workers and of residents.

In all of its work, the Committee made an effort to keep the public informed of its activities, especially those persons who were concerned that their health may have been affected by living near the landfill site. This effort was facilitated by interaction with members of the Upper Ottawa Street Residents Association and their consultant, Dr. Steven Safe.

This chapter discusses the advantages and disadvantages of approaches that have been developed and used in various landfill investigations. The discussion of the state of the art for this field of research is followed by a description of the study plan formulated for the Upper Ottawa Street landfill site. The Committee's approach to investigating this site builds upon the limited but growing knowledge acquired in previous studies conducted at other landfills.

B. CURRENT SITUATION IN NORTH AMERICA

In 1979 the Ontario Ministry of the Environment identified 1,500 municipal and private landfill sites that had been operated and closed before waste management legislation was passed in 1970.(4) Varying degrees of environmental problems were discovered at 11 of these sites. In addition, an investigation of priority industrial waste sites identified some offsite adverse environmental impact at 11 of 52 sites. The Ministry reports that remedial measures have been taken at these problem sites.

It is estimated that 1,500 landfill sites are presently in operation in Ontario.(5) Of this number, only seven municipally owned landfills and one privately owned landfill have been licensed by the provincial government as certified receivers of liquid industrial wastes.(6) A study for the Ontario Waste Management Corporation estimated that industries generate 1.5 million tonnes annually of liquid industrial and hazardous waste in Ontario that cannot be handled effectively by conventional municipal treatment and disposal sites such as sanitary landfills, municipal incinerators and sewage treatment plants.(7) In 1982, the federal government estimated that at least 3.2 million tonnes of hazardous wastes are generated each year in Canada.(8)

The Ontario Waste Management Corporation has proposed constructing a central facility consisting of incineration, physical and chemical treatment and landfill for treated residues, with an initial capacity of 150,000 tonnes/year (i.e., 30,000 tonnes of organic waste and 120,000 tonnes of inorganic wastes) and with provisions for future expansion up to 300,000 tonnes/year if necessary. In conjunction with this activity, the Ontario Ministry of the Environment is developing new waste management regulations to improve the process of establishing, operating and closing landfills in the province.

Similar increasing concern about regulation of chemical disposal sites exists in the United States where the problem is of much larger dimensions. It is estimated that somewhere between 130 and 400 million tonnes of hazardous wastes are generated annually in the United States.(9) There are 4,818 treatment, storage and disposal facilities in the United States authorized for active use under the Resource Conservation and Recovery Act of 1980, but the number of uncontrolled sites (i.e., open dumps, landfills, bulk storage containers and surface impoundments) exceeds 20,000. Under the Federal Superfund Act of 1980, the Environmental Protection Agency (EPA) has designated almost 800 disposal sites in its National Priority List for remedial attention because of serious environmental hazards associated with these sites.

C. LANDFILL SITE CHARACTERISTICS

Each waste disposal site is unique and presents a different set of problems for investigators. No two landfills receive the same types or volumes of wastes. For example, the Love Canal site received millions of litres of liquid chemical wastes from a chemical manufacturer in contrast to many municipal landfills in Ontario where the largest waste component is solid household garbage. It may be that many municipal landfills are relatively non-hazardous, because the liquid industrial wastes are of greater concern than household garbage. There is, however, a lack of documentation and factual information about the nature and amount of wastes at most sites. Many of the landfills that are considered hazardous at the present time began operations in the 1950s and continued landfilling for 20 or 30 years. It is not possible to reconstruct with any accuracy the history of dumping at the sites where records were not kept.

The disposal of wastes in barrels, the processing and treatment of various wastes and onsite burning were practiced differently at each site. A typical disposal method was to pour liquid wastes onto solid garbage. At some sites the wastes were routinely compacted and covered with soil. The way in which landfilling operations were conducted will influence future chemical migration from the site.

Some landfills service industrial urban areas while others are located in farming communities where different, although not necessarily less hazardous, waste streams can be anticipated. It cannot be assumed, however, that the wastes disposed of at any particular site are generated by local industry. With growing concern about the industrial waste problem during the 1970s, tighter government regulation of some waste disposal sites led to increased use of other sites and long distance transport of wastes away from the jurisdictions in which they were generated.

For landfills that are located in cities, and particularly where housing has been constructed on top of closed sites, the potential for direct human exposure to landfill contaminants is likely to be greater than for landfills situated in unpopulated areas.

Landfills that are situated on clay provide better protection against the seepage of leachate (i.e., liquid produced by the percolation of water through landfill wastes) into groundwater than do those sites situated on more porous sand or fractured rock. Very often, landfills are located near bodies of water, which provide pathways for transporting landfill contaminants farther distances from the site.

D. ANALYTICAL TECHNIQUES

Since it is usually impossible to assemble a well-documented history of waste deposition at a site, the first step in any landfill study is to identify and quantify the chemical substances contained within the landfill and those migrating from it.

The chemists of the early 1950s were able to detect and quantify organic chemicals only if these were present in a relatively simple mixture at concentrations of the order of one part per thousand. Because of advances in instrumentation for the analyses of chemicals in trace quantities, toxic organic substances can now be detected and quantified routinely at levels of one part per billion (ppb) or even lower.*

The increase in sensitivity of analytical methods from 1958 to 1968, which corresponds to a factor of approximately one million, was due primarily to the introduction of new detectors used with various forms of gas chromatography and improved clean-up procedures. This progress permitted the detection of chemicals at very low levels and in complex mixtures.

The main recent gains have been in methods for specific identification of chemicals in trace amounts. In particular, the coupling of gas chromatographs to mass spectrometers (GC-MS) interfaced with digital computers has provided a powerful tool in which many chemicals present in complex mixtures can be separated, identified and quantified.

Compound identification is usually accomplished by computer matching of the mass spectrometric spectra of a sample with the spectra of known compounds contained in a computer library compiled by the United States Environmental Protection Agency and the National Institute of Health. That library contains the spectra of some 36,000 compounds. It is estimated, however, that there exist 53,000 chemicals of known commercial significance, and more than five million substances are described in the chemical literature.(10) Consequently, many compounds cannot yet be identified using this analytical method. Also, compounds present in trace amounts may go undetected if they are not specifically targeted in the analyses.

In spite of the advances made in the field of analytical chemistry, difficult problems remain, and these complicate the identification and measurement of landfill chemicals. In these studies it is important to sample correctly, particularly with respect to air samples. Landfill samples of water and soil are often characterized by the presence of oily substances that are difficult to remove from the sample and that may, therefore, hide the presence of other compounds.

A different approach to the detection of toxic hazards is biological testing in which mutagenicity assays are used to screen chemical mixtures for potential carcinogenicity.

The Ames assay, which is the most commonly used of the mutagenicity tests, is a simple, rapid, widely used and relatively inexpensive test that shows whether a chemical or a mixture of chemicals causes mutation in certain carefully constructed strains of bacteria. Since most carcinogens are mutagens and most non-carcinogens are non-mutagenic, this provides a preliminary indication of the presence or absence of carcinogens. However, the assay itself does not measure quantitatively the cancer potency of a substance nor does it provide an estimate of health risk to humans.

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* To place such small concentration levels in perspective, one part per billion with respect to distance corresponds to one millimetre in one thousand kilometres or, with respect to time, 3/100th of a second in one year.

E. TOXICOLOGICAL ASPECTS

Scientists are able to identify trace amounts of compounds but there is a lack of data concerning the biological effects of the low concentrations that are typical of landfill emissions. There are several reasons to suggest that knowledge of toxic effects associated with the low exposures common to both urban air generally and landfills will continue to be limited for some time to come.

What is known about the toxic effects of chemicals has usually been learned from animal studies involving high doses and small numbers of animals as well as episodes of industrial or other types of human exposure. For example, with cancer assays, which are animal studies undertaken to determine if a chemical causes cancer, 100 animals of each sex are ordinarily used in the control groups and in two exposed groups. These types of assays are severely limited in their sensitivity and are capable of detecting the effects of a carcinogen only when the dose is high enough to induce cancer in a percentage of the animals that is higher than the natural background incidence for tumors.(11) Since studies of this sort require at least two years of work and cost over $500,000 per chemical there is little prospect for routine studies involving smaller doses and larger numbers of animals.

Even if it were possible to determine the effect of low level exposure on experimental animals, serious problems are encountered in trying to extrapolate toxicity test results from animals to humans.(12) The general approach to toxicity testing has been to determine the maximum exposure that failed to produce a toxic effect in experimental animals and divide by 100 to provide a safety factor for humans although this factor varies with the purpose of the testing.

Toxicity information is available for only a small fraction of the 53,000 chemicals in commercial use. For most of the compounds for which some toxicity information exists, environmental standards for permissible exposures have not yet been established.

Little is known about the effects of multiple exposure or toxicological interactions of chemicals. Classical toxicology has considered chemicals one at a time with no allowance for the fact that persons are exposed simultaneously to various levels of a large number of individual toxic substances. This is a particularly serious issue for landfill studies and other situations where complex mixtures of chemicals are encountered.

Threshold limit values (TLVs) which represent the maximum 'safe' permitted exposures for workers to chemicals during an eight hour working day or 40 hour working week, have been set for many industrial chemicals. However, persons living near landfill sites or other sources of pollution generally experience lower levels of exposure over longer periods of time as contrasted to maximum permitted exposures for workers. Additionally, workers are usually healthy individuals whereas the general population also contains the young, the infirm and the elderly, who may be more sensitive to the effects of exposure.

A third complication arises when a landfill has been shown to contain toxic substances, but the actual current exposure of residents is no higher than that frequently found in an urban environment.

F. ROUTES OF TRANSPORT AND EXPOSURE

Even if the presence of toxic chemicals within a landfill site is established, the situation is not hazardous unless humans come into contact with these substances. Humans can be exposed to hazardous wastes by ingestion, inhalation or dermal contact. The likely routes of transport are the leaching of chemicals into groundwater, runoff into surface waters and airborne emissions of gases and particulates. Other routes of exposure include the adsorption of compounds into soil and the bioaccumulation of chemicals in plants and animals that provide food.

F1. CHEMICAL CHARACTERISTICS AND PROCESSES

An important factor influencing offsite migration is the physical and chemical properties of the individual compounds in the chemical wastes. These will be discussed in this section in the context of the various routes of transport.

Chemicals may be transformed by chemical reactions such as oxidation and reduction or they may be degraded by biological processes involving bacteria and fungi. Photochemical decomposition by light will not occur within landfills but may take place following emission, especially in ambient air. Usually these processes have the effect of breaking down the original compounds into less toxic substances, but this is not always the case. Not very much is known, however, about the rate and extent of these processes in the dark, wet, anaerobic conditions of landfills, but they have an obvious impact on the nature and concentration of hazardous substances and on the transport of and potential exposure to humans. Some compounds such as PCBs are resistant to chemical transformation and remain very stable.

F2. GROUNDWATER MIGRATION

Of the common routes of transport, contamination of groundwater is seen to be the most serious threat to human health. Groundwater contamination may affect large populations if the aquifer is used as a source of drinking water. Chemicals generally pass slowly into groundwater and the flow of groundwater itself may be very slow. For example, the range of calculated transport times for a chemical in groundwater to flow one kilometre through sand may be anywhere from 10 to 1000 years.(13) The potential for human exposure can be long term and is unpredictable. Contamination may persist because many chemicals in groundwater resist biological and chemical degradation.

Groundwater contaminated by landfill chemicals is referred to as leachate and the zone of contamination is the groundwater plume. A number of factors control the rate of leachate production and chemical migration out of the landfill mass and into groundwater. Especially important is the amount of precipitation that penetrates the landfill. If the site is covered by a completely impermeable cap, leachate will eventually cease to be generated, unless some of the landfill mass is located below the water table.

The mobility of landfill-based organic chemicals is primarily dependent on two related properties: water solubility and sorption potential. The latter relates to the way in which substances partition themselves between water and organic matter contained within the waste or present in soils. A chemical such as chloroform is highly soluble in water and has a low sorption potential; therefore, it will be leached rapidly and will readily migrate in solution from the disposal site. In contrast, the hydrophobic substance, naphthalene, has a low water solubility and a relatively high sorption potential. As a result, it will migrate more slowly because of its tendency to be retained (i.e., adsorbed) by other waste materials in the landfill or in soils.

The mobility of heavy metal ions is greatly dependent on pH (i.e., whether leachate is acidic or alkaline) and on the nature of the materials co-deposited with the metals. In general, heavy metals are retained within landfills in which domestic garbage is present.(14)

The rate and routes of groundwater transport of landfill chemicals are dependent on the hydrogeological setting in which the landfill is located. Factors which determine the shape and size of contaminated plumes include subsurface geological structures (i.e., sand, clay, fractured rock), aquifer permeabilities, groundwater flow patterns and the nature and concentration of contaminants. In many situations where groundwater contamination is a potentially serious problem, hydrogeological studies are needed to map the contaminated plume and to predict its future direction and rate of movement.

F3. SURFACE WATERS

Landfill contaminants enter water bodies by direct surface runoff and discharge into groundwaters. Mixing and dilution of hazardous chemicals, biodegradation of chemicals by microorganisms and chemical oxidation occur much more rapidly in surface waters than in groundwater. In addition, certain wastes will evaporate into the air. Some hazardous substances cannot be biologically or chemically degraded in any environmental setting. These include polychlorinated biphenyls (PCBs), a class of compounds which often tend to accumulate in the sediments of streams, ponds and lakes.

Long distance transport of landfill contaminants in rivers, for example, can potentially expose more people than is the case with slow moving and more geographically limited groundwater plumes. Since surface waters are utilized as drinking water sources and for recreational activity such as swimming, human exposure can be both by ingestion and contact with the skin.

F4. AIR

Hazardous waste chemicals may enter the atmosphere in the vapour phase or be adsorbed on dust particles or aerosol droplets. Organic compounds that have high vapour pressures and low water solubilities can be expected to evaporate quickly. For example, the time necessary for 50 percent of dissolved chloromethane to evaporate from shallow depth within the ground (i.e., the estimated value of the aqueous evaporation half-life) has been estimated to be about 20 to 30 minutes, compared to five hours for benzene and three days for DDT.(15)

The rate of emission of hazardous chemicals will be accelerated when large amounts of landfill gas (i.e., methane) are formed by the anaerobic degradation of organic material found in household garbage. The presence of a clay cap, which may be essentially impenetrable to precipitation, will not contain the landfill gas since cracks invariably develop through which the gas readily escapes. In certain situations, the landfill gas itself may be an explosion hazard and should be collected and burned. The co-deposition of industrial and household wastes presents special problems that must be carefully assessed and, if necessary, remedial action should be taken.

It is often difficult to establish the degree of hazard associated with exposure to airborne landfill contaminants because these are generally the same volatile compounds that are present in urban air from non-landfill sources. Although the concentrations of volatile compounds emitted from landfills are often low, the actual total mass loading of the environment over a period of time may be substantial and comparable to industrial atmospheric emission in the same area.

At landfills where large amounts of solid wastes have been deposited, the problem of hazardous chemicals adsorbed on particulates can be significant. Polycyclic aromatic hydrocarbons (PAHs), which have a high sorption potential and are known to cause certain kinds of cancer, are of special concern in this regard.

F5. FOOD

Humans are exposed to landfill contaminated food from plants, animals and fish which come into contact with the hazardous wastes in the soil or directly on the disposal site. Plants, animals and fish can store high concentrations of chemicals, and this process of bioaccumulation in the food chain can expose humans by ingestion to higher concentrations of hazardous wastes than would be transported in either water or air.

G. HEALTH STUDIES

G1. EPIDEMIOLOGY

Epidemiology is the science of discovering and interpreting disease patterns in groups of people. It has been the approach most commonly used to study human exposure to landfill chemicals. Epidemiological studies are designed to assess the existence of any illness in the exposed population (e.g., persons living and working near the landfill) in excess of what exists in a comparison or control population. If such an excess of illness in the landfill group can be demonstrated, further studies must determine whether this morbidity can be associated with exposure to chemicals in the landfill.

Epidemiological investigations of chemical disposal sites have most often been initiated in response to public alarm about a landfill site being environmentally hazardous or the observation of an unusual cluster of disease in a geographic area within a short period of time. Residents at Love Canal observed unusually dramatic occurrences including the backup of chemical wastes into swimming pools and the eruption of barrels of intact chemical wastes into a school playground, which led to concern that their neighbourhood was unsafe.(16) In Woburn, Massachusetts, a perceived high number of childhood leukemia cases was brought to the attention of public health officals and, although these cases could not be associated with exposure to chemical wastes, it is obvious that such clustering effects attract community attention.(17)

G1.1 Study Designs

A number of different approaches to epidemiological studies have been used, depending on the nature of the problem being investigated. In assessing the health consequences of landfill exposure the most commonly used method is the so-called cross-sectional or prevalence study in which the frequency of disease among an exposed population is compared to that of an unexposed control group.

The use of a health questionnaire to obtain the self-reports of landfill workers and residents has become an important element in these studies.(18)

G1.2 Problems Associated with Landfill Epidemiological Studies

The problems commonly experienced in epidemiological studies include the difficulties of studying small populations, the effect of confounding factors (such as age, smoking, drinking, etc.) the control of bias, and the selection of an appropriate control group.(19,20,21)

A particular concern of epidemiological studies of landfill populations is the identification of exposure levels. The actual chemical exposures experienced by landfill residents rarely can be fully documented for practical reasons. Most exposures involve numerous chemical wastes, not a single substance, and these compounds are difficult to detect and quantify because they are often present in low concentrations. In contrast to chemical exposures occurring in the work place, acute health effects, which often lead to rapid hazard identification, are rarely the result of exposure to landfill chemicals.

A further complication of exposures is that the latency period between the time of first exposure and the time illness becomes apparent may be many years for such health effects as kidney disease and cancer. At the time that such health effects are observed, it may be impossible to reconstruct past levels of exposure and, therefore, to draw conclusions concerning the causal relationship between exposure and disease.

An additional problem relating to levels of exposure is the identification of the population at risk, which requires knowledge about individual exposures and that of subgroups. The exposure of children who may live and attend school near a landfill where wastes are processed between the hours of nine and five, may be quite different from that of employed adults who are absent from such exposures during working hours.

G2. CLINICAL AND LABORATORY TESTS

At the present time there are no tests that are capable of unambiguously detecting the biological effects of low-level chemical exposures typically experienced by people living near landfills. Clinical and laboratory assessments are usually targeted at certain organ systems and diseases; in contrast, the health complaints of landfill residents are those of a 'non-specific' nature such as headaches, eye irritation, sore throat and fatigue.

Cytogenicity testing provides an interesting example of the limitations of using clinical methods to detect environmental disease. Cytogenetic tests (i.e., the study of breaks in and other damage to chromosomes) have been used for population monitoring.(22) While relatively few well conducted human chromosome studies have been carried out there is general agreement among scientists working in this area that:

a) there is a great deal of variation in the amount of detectable chromosome damage among individuals due, at least in part, to such things as viral infections, x-rays, smoking, age and sex of the individual;

b) exposure of populations to chromosome damaging chemicals or radiation increases the amount of damage observed in that population;

c) on a population basis an increase in chromosome damage is an indication that the population has been exposed to chromosome-breaking agents and is likely, therefore, to be at increased risk of cancer;

d) the level of chromosome damage in an individual is not a valid predictor of future malignancies or other health problems for the individual.

To further complicate the interpretation of human chromosome damage, many of the studies reported in the literature have been conducted without due attention to adequate controls and/or technique.

The most publicized chromosome study was a sister chromatid exchange (i.e., microscopic examination of cultured and stained white blood cells) performed on 36 Love Canal residents in 1980 under the auspices of the Environmental Protection Agency (EPA) and repeated by the Centres For Disease Control (CDC) in 1984. The first study claimed to see unusual chromosome damage in Love Canal residents, but these findings were discredited.(23) The subsequent tests conducted by CDC found no significant differences between Love Canal residents and a control group. However, not all of the original subjects agreed to participate in the second test and, by the time CDC did this work, the Love Canal residents had been removed from the exposure for several years.(24) The episode caused great anxiety among residents and added little to the scientific understanding of studying chemical exposures by cytogenetic methods.

Unless detailed information is known about the chemical exposures, it is unlikely that clinical and laboratory studies will detect exposure related disease in a landfill population. While these approaches may not be beneficial for initial screening or as early indicators of toxic disease in landfill populations, both clinical and laboratory techniques in certain situations could prove extremely effective in verifying the results of epidemiological investigations and providing diagnostic information on the severity of diseases.

H. RISK ASSESSMENT

Assessing the risk for a population of developing disease because of landfill exposure has been used primarily to estimate future cancer risk. Various qualitative and mathematical models have been designed, all of which require estimates of exposure and estimates of a toxic dose (i.e., sufficient duration and intensity of exposure to cause an adverse effect).(25)

A complete assessment of exposure requires knowledge of the exact nature and volume of chemicals deposited in the landfill, the rates of chemical release and transportation into air, soil and water and quantitative analyses of concentrations of individual compounds. Detailed information of this type does not exist for most landfills; therefore, the quality of exposure data used in risk assessment is questionable.

In some situations, the measurements of chemicals in tissue and body fluids provide a good approach for estimating the levels of exposure. The use of animal toxicity data, and its concomitant problems with the unknown effects of low dose exposure and interspecies differences, combined with the unknown effects of exposure to combinations of chemicals, demonstrate the shortcomings involved in calculating toxicity estimates for risk assessment.

Work has also been done on 'environmental reconnaissance', which is the assessment of changes in plants and animals around a landfill. Plants and animals could be examined for gross pathology or chemically analyzed for environmental contamination. Such findings could act as 'early warning' indicators for human risk.

I. PUBLIC REACTION AND PARTICIPATION

The study of health and environmental problems associated with landfill sites requires the participation of people who live and work near the site with scientists and government officials. Beginning with Love Canal, and reported at almost every subsequent site where research was conducted, the relationships among these groups could be characterized as frustrated and distrustful. The role of the media, particularly the local media, in publicizing these events is believed to be important.(26) Work is being done on documenting and analyzing the negative social and psychological effects of chemical exposures.(27)

From the viewpoint of workers and residents who believe that their health and that of their families has been damaged, government is not seen as being credible because officials are usually pressured into studying landfill problems by organized citizen groups. The popular belief is that government will downplay or conceal problems in order to avoid political embarrassment or significant government spending.(28) Scientists are perceived to be in collaboration with government or other interest groups, to be insensitive to the community's concerns and unwilling to provide 'straight' answers.(29)

Government officials, who presumably attempt to incorporate scientific information in decision making and whose policy responses towards landfill issues are constrained by budgetary considerations, may perceive citizens to be unreasonable and motivated by economic interest or publicity.

The scientific community does not have answers to most of the questions raised about landfill exposure. Most of the scientific research involved in this field is government sponsored, and this adds a further complication in the public perception of the scientists' role.

Various remedies to these problems of perceptions and behaviour have been suggested. These include steps to involve affected workers and residents in meaningful ways in the investigation of landfills, rather than merely informing them of the progress of such work. Other proposals call for a change in government policy concerning the release of information and argue that the citizen's right to know is particularly justified in matters of environmental health and safety. Some critics suggest that the conflict would be reduced if scientists could agree among themselves on the interpretation of findings and could successfully communicate technical information to the public.

3. STUDY PLAN FOR THE INVESTIGATION OF THE UPPER OTTAWA STREET LANDFILL SITE

3.1. INTRODUCTION

Love Canal was the only similar experience of which the Committee had knowledge at the outset of its investigation. It became clear from the beginning of the Upper Ottawa Street landfill investigation, however, that there were very few real similarities between it and the Love Canal sites. Love Canal was the repository of chemical manufacturing wastes, including dioxins and PCBs, to which persons had been directly exposed for twenty years. Such is not the case at the Upper Ottawa Street site.

Nevertheless, the Upper Ottawa Street landfill could be described as a combination of the worst possible features of a site both in terms of potential environmental contamination and obstacles to research. Some of the major obstacles recognized in the development of the study plan include: the lack of knowledge about the types and amounts of wastes deposited at the landfill and the concentrations of compounds to which persons may have been exposed when the site was operating; ready access for the transport of landfill contaminants in the creek which flows through the site or in the fractured bedrock upon which the landfill is situated; and a "difficult to define" exposed population consisting of a small number of workers and residents who, for the most part, did not live in the area until 1976.

J2. CHEMICAL CONTENT OF THE LANDFILL

The first step planned in the investigation was an extensive review of existing records, anecdotal and all other known sources of information, in order to obtain an accurate description of the types and amounts of wastes. Of particular interest were the large volumes of liquid wastes deposited at the site. Knowledge of the chemical content of the landfill would have provided guidance for the chemical analyses and a basis for designing the health studies and interpreting the results.

Some attention has been given to the chemical content of the landfill by analyses of core samples from boreholes penetrating the landfill itself. There are two reasons for doing this. Analysis of substances migrating at the present time does not provide a complete picture of the chemicals to which residents and workers may have been exposed prior to the closure and covering of the landfill. There is also the question of whether or not there are chemicals buried in the landfill that are not being detected at present but which could be expected to migrate sometime in the future.

The Committee decided that it was neither practical nor affordable to drill the hundreds of boreholes that would be required to obtain a complete picture of the buried wastes. It was possible, however, to obtain core samples from the drilling work required to replace existing broken installations.

J3. CHEMICAL ANALYSES

The second stage of the investigation was to examine the environment around the landfill. The major foci of this work were planned to be on air, surface water, leachate and groundwater.

J3.1 Air

The Committee identified airborne contamination as the most important potential route of human exposure to toxic chemicals at the Upper Ottawa Street landfill. Direct contact with the landfill is unlikely to be a major factor because housing and recreational facilities are not on the site, and the ingestion of surface or ground waters is also unlikely because these are not used as sources of drinking water.

The Committee's air testing program was designed to obtain information on two aspects. The first was the chemical content of gas emitting directly from the landfill in gas vents installed on the site. Landfill gas is being generated within the site itself and of particular concern are the potentially toxic substances in the gas resulting largely from industrial wastes that were deposited with the domestic wastes. The second relates to the quality of the air in nearby neighbourhoods. Chemical analyses were carried out on air samples collected from locations upwind and downwind of the landfill and, for comparison, at other Hamilton sites.

The air tests were designed to detect the volatile organic compounds, which are among the most toxic chemicals likely to be encountered in airborne exposure. In addition, special attention was given to the analyses of polycyclic aromatic hydrocarbons (PAHs) in landfill gas. Although PAHs are of low volatility, they may be present on particulates in ambient air.

A major testing program was also undertaken in conjunction with experiments on the feasibility of collecting and burning landfill gas. This work involved determining the volume of landfill gas being produced, analyzing the chemicals contained in the gas and assessing whether the gas could be flared safely.

J3.2 Leachate and Surface Water

The Committee decided that extensive organic analyses of leachate and surface water were also required. It is the organic compounds that are likely to be the most dangerous toxic substances contained within the landfill and, as in the case of air testing for toxic chemicals, their identification in the leachate and surface water was considered to have high priority. One reason for this is that a cover has been placed on the closed landfill and, consequently, air tests might not detect many of the compounds to which persons may have been exposed when the landfill was operating. Also, compounds that might not be detected in the air because of their low volatility might be found in the leachate.

An additional important factor calling for extensive leachate analysis is that leachate flows from springs on the mound into Red Hill Creek, which forms the northern boundary of the landfill, thereby potentially exposing people downstream to landfill contaminants. Furthermore, leachate from the south, east and west sides of the landfill is now being collected and piped into the sanitary sewer system. Although dilution will be large, it is, nevertheless, important to know the extent to which pollutants of a toxic nature are entering the sewage system from the site.

J3.3 Mutagenicity Testing

The Committee recognized that a major concern among the workers and residents is the possibility that exposure to landfill chemicals may cause cancer. A decision was made to undertake a program of Ames assays of leachate, air particulates and landfill gas, although there is as yet no generally accepted methodology for the latter application. This type of biological assay provides additional data, which can be useful in supplementing the information obtained from analytical chemistry work or can be used in the absence of chemical information.

J3.4 Groundwater

The Upper Ottawa Street landfill sits on fractured bedrock, therefore, there was concern that the site is polluting the groundwater and that this contaminated plume would present serious environmental problems if it begins to seep through the nearby escarpment face. Little is known about the flow characteristics of groundwater in bedrock, and it became apparent that a thorough hydrogeological investigation of this site was a research project not appropriate for commercial consulting firms. The foremost groundwater research institute in Canada was retained to conduct an extensive, pioneering study of the hydrogeological aspects of the Upper Ottawa Street landfill. The study involved the measurement of groundwater flow rates as well as extensive chemical analyses to map the contaminated groundwater plume.

J4. HEALTH STUDIES

The third and most critical aspect of the Committee's investigation was the health studies. The plan for the health studies of landfill workers and residents consisted of four components: toxicological assessment of detected chemicals to assist in designing the health studies and interpreting the results; an assessment of the feasibility of conducting epidemiological investigations; designing the workers study, and designing the residents study.

J4.1 Toxicological Work

The Committee recognized that in order to have as clear a focus as possible for its health studies, detailed toxicological information was needed on the many compounds detected and/or tentatively identified in its analytical work of the Upper Ottawa Street landfill. The toxicological work involved three separate aspects.

In the early stages of the Committee's investigation the toxicologist consultant reviewed the numerous chemicals detected by qualitative chemical analyses and identified the most potentially toxic compounds to be targeted in future analyses.

A second program involved reviewing the 'inherent' toxicity of all the compounds identified in the chemical analyses even though the actual conditions of human exposure are not known. The consultants provided an assessment on the types of disease that might be expected if persons had been exposed to certain chemicals in sufficiently high levels and for sufficiently long periods of time. This toxicological assessment, which represented the extent of knowledge about these chemicals, was used as one guide in designing the health studies.

The third aspect of the toxicological work was the assessment of the implications for human health of exposure to the observed concentrations of chemicals identified in the analyses of leachate, sediments, surface waters and landfill gas. The consultant developed these toxicological assessments on the complete analytical findings that became available at the end of the Committee's investigation.

J4.2 Designing Health Studies of Workers and Residents

An Advisory Health Group was established to direct work on designing the health studies. This group requested an assessment of the feasibility of an epidemiological investigation of the health impact of the Upper Ottawa Street landfill on workers and local residents. Designing health studies of the type needed was hindered because a) there is no established methodology for such studies, b) the duration of exposure for most residents is less than 10 years, which is too short a time for potential chronic effects such as cancer to be detectable, and c) the likelihood of being able to establish a cause and effect relationship between illness and the landfill is small because of the problems of isolating landfill exposure from other types of chemical exposure.

It was decided to conduct separate health surveys of cohorts of workers and residents involving: questionnaires administered in the respondents' homes by professional interviewers; the use of control groups for comparing the health of landfill workers and residents to similar groups of people elsewhere in Hamilton; and medical chart abstraction studies, which involved examining the medical charts kept by the family doctors of study participants. The study of workers was planned to precede that of landfill residents in order to generate hypotheses concerning the effect of landfill exposure on health from the potentially higher dose exposure of workers that could be tested in a subsequent larger scale study of residents.

In designing the health studies, particular emphasis was given to two major problems: the lack of exposure information and the bias associated with self-reports of health problems.

In the absence of detailed knowledge about the types and concentrations of chemicals to which workers and residents may have been exposed, the questionnaires were designed in such a way as to detect a wide range of possible health effects related both to the identified chemicals and to chemical exposure generally. The sampling strategies were designed with a view to using duration of residence and proximity to the landfill as indirect indicators of exposure for the residents study, and onsite jobs versus offsite jobs as indirect indicators of exposure for the workers study.

Detailed medical chart abstraction studies were designed in conjunction with health studies of landfill workers and residents for the purpose of addressing recall bias. In the case of the workers study, the objective of the chart abstractions was to verify the accuracy of self-reports of individual respondents. The objective of the residents chart abstraction study was to ascertain the amount of recall bias through a comparison of general trends of over- and under-reporting between landfill residents and controls.

J4.3 Clinical Studies and Laboratory Tests

Clinical and laboratory tests were not included in the health studies designed and implemented during the Committee's investigation because what was known about exposure indicated that diagnostic testing would not be useful. For example, the kinds of health problems that landfill residents had complained of, such as sore throats, colds, headaches and earaches, are nonspecific conditions for which information can be collected more efficiently by questionnaire than by laboratory testing. Long term, serious problems such as cancer could not be expected to be detected clinically in landfill residents because few residents had long term exposure to the site and too short a period of time has passed for possible exposure-related cancers to develop. It was decided, however, that physical examinations and other medical studies would be carried out if the results of the epidemiological studies identified health conditions in landfill residents that should be further investigated by the use of such tests.

J4.4 Risk Assessment

The Committee considered the feasibility of risk assessment analyses with the objective of providing an estimate of future cancer risk that residents living around the Upper Ottawa Street landfill might have incurred from their past exposures to offsite chemical contaminants.

J5. MISCELLANEOUS STUDIES

During its investigation, the Committee also conducted limited research into four additional areas. In no case were the findings helpful in providing additional information about landfill chemicals or exposure-related health conditions.

The purpose of the first study was to determine if geophysical techniques were available to detect barrels of chemical wastes that might be buried in the site. Ground-imaging radar, magnetometer instruments and electromagnetic techniques were tried but failed to provide the information.

A small-animal study was undertaken to obtain information on whether the health of animals exposed to the landfill had been affected. An examination of the animals and analyses of tissues suggested that the animals did not come into direct contact with significant amounts of toxic chemicals from the landfill.

A study involving the review of student absenteeism records at Blessed Kateri Tekakwitha School, which is located across the street from the landfill, and two schools located elsewhere in Hamilton, was designed to address public concern about the safety of children attending schools near the site. The results indicated that there is little difference in average absenteeism rates among the schools.

The fourth study was an examination of gas company records for the purpose of determining if households located near the landfill were complaining of problems that might be associated with methane gas migration from the site. The majority of the complaints were routine and involved service repairs. Of the unresolved complaints, no clustering by time or location was observed.

Further details of these studies are presented in Appendix 1.

References

1. P.J. Landrigan, "Epidemiologic Approaches to Persons With Exposures to Waste Chemicals," Environmental Health Perspectives 48 (1983): 93-97.

2. C.W. Heath, "Field Epidemiologic Studies of Populations Exposed to Waste Dumps," Environmental Health Perspectives 48 (1983): 3-7.

3. Universities Associated For Research and Education in Pathology, Inc., Health Aspects of the Disposal of Waste Chemicals, Draft of a Final Report to be published in the spring of 1986 by Pergamon Press Inc., Elmsford, New York. (hereafter cited as UAREP)

4. Ontario, Ministry of the Environment, Blueprint for Waste Management in Ontario, Toronto, June 1983, p. 27.

5. According to a survey conducted by the Waste Management Branch of the Ontario Ministry of the Environment in 1979.

6. J. Jackson, P. Weller, and the Waterloo Public Interest Research Group, Chemical Nightmare: The Unnecessary Legacy of Toxic Wastes (Toronto: Between The Lines Press, 1982), pp. 25, 68 and 111.

7. Proctor & Redfern Limited, Waste Quantities Study, prepared for the Ontario Waste Management Corporation, Toronto, August 1982, p.43.

8. Jackson, Weller and OPIRG, Chemical Nightmare, p. 25. (see reference 6)

9. UAREP, pp. 1-18. (see reference 3)

10. UAREP, pp. 6-38. (see reference 3)

11. Littlefield, N.A. et al. "Effects of Dose and Time in a Long-Term, Low Dose Carcinogenic Study" in: Stoffa, J.A. et al. Innovations in Cancer Risk Assessment. (ED_{01} Study), Pathtox Publishers Inc., Park Forset South, IL. pages 17-34.

12. UAREP, pp. 6-23. (see reference 3)

13. UAREP, pp. 3-19. (see reference 3)

14. F.G. Pohland, J.P. Gould, R.E. Ramsey, and D.C. Walters, "The Behaviour of Heavy Metals During Landfill Disposal of Hazardous Wastes," in Land Disposal of Hazardous Wastes: Proceedings of the Eighth Annual Research Symposium, ed. David W. Schultz (U.S. Environmental Protection Agency: Publication No. 600/9-82-002, March 1982), 360-371.

15. UAREP, pp. 3-25. (see reference 3)

16. Michael Brown, Laying Waste: The Poisoning of America by Toxic Chemicals, (New York: Washington Square Press, 1981), pp. 3-28.

17. United States, Center For Environmental Health: Chronic Diseases Division, Cancer in Woburn, Massachusetts, prepared for Centers for Disease Control and the Massachusetts Department of Public Health, September 16, 1981.

18. "Morbidity Study at a Chemical Dump - New York," Morbidity and Mortality Weekly Report 30: 24 (June 26, 1981): 293-294.

19. D. Baker, et al., "Health Impact of a Toxic Waste Disposal Site," Abstract No. 194 from the Tenth Scientific Meeting of the International Epidemiological Association (Vancouver, 1984).

20. K.P. Satin, et al., "Health Effects in a Population Living Near An Acid Petroleum Sludge Disposal Site in California," Abstract No. 254 from the Tenth Scientific Meeting of the International Epidemiological Association (Vancouver, 1984).

21. W. O. Spitzer, Final Report of A Study of the Health Status of Residents of the Junction Triangle, Toronto, 1984.

22. A. D. Bloom, ed., Guidelines For Studies of Human Populations Exposed to Mutagenic and Reproductive Hazards, Proceedings of Conference Held January 26-27, 1981 in Washington D.C., (White Plains, New York: March of Dimes Birth Defects Foundation, 1981).

23. Gina Bari Kolata, "Love Canal: False Alarm Caused by Botched Study," Science 208 (June 13, 1980): 1239-1242.

24. C. W. Heath, et al., "Cytogenetic Findings in Persons Living Near the Love Canal," Journal of the American Medical Association 251: 11 (March 16, 1984): 1437-1440.

25. UAREP, pp. 6-36. (see reference 3)

26. Robert G. Hughes and Steven P. Schwartz, "Communities and Toxic Wastes: Further Evidence," Journal of Public Health Policy (December 1983): 514-518.

27. Urmas Madisso, A Synthesis of Social and Psychological Effects of Exposure to Hazardous Substances, Environment Canada: Ontario Region, Inland Waters Directorate, January 1985.

28. Lois Marie Gibbs, "The Need for Effective Governmental Response to Hazardous Waste Sites," Journal of Public Health Policy (March 1981): 42-48.

29. Adeline Levine, "Psychosocial Impact of Toxic Chemical Waste Dumps," Environmental Health Perspectives 48 (1983): 15-17.

PART 2

RESULTS OF CHEMICAL ANALYSES

Chemical Content of the Landfill

Chemical Content of Leachate, Surface Waters
and Sediments

The Direction and Rate of Flow
of Groundwater

The Chemical Content of Groundwater

Chemicals in Landfill Gas and Surrounding Neighbourhoods

Implications for Human Health of Exposure to
Chemicals from the Landfill

CHAPTER 4

CHEMICAL CONTENT OF THE LANDFILL

TABLE OF CONTENTS

Page

A. INTRODUCTION 51

B. AMOUNT OF WASTES 51

C. DESCRIPTION OF WASTES 52

D. STEEL WASTES 53

E. CHEMICAL ANALYSES OF LANDFILL CONTENTS 54

  E1. INTRODUCTION 54

  E2. CORE SAMPLES 55

    E2.1 Analytical Methods 55
    E2.2 Findings 57

  E3. STEEL WASTES 58

    E3.1 Analytical Methods 58
    E3.2 Findings 61

      E3.2(a) Polycyclic Aromatic Hydrocarbons 61
      E3.2(b) Heavy Metals 63
      E3.2(c) Other 63

Figures Page

6 Location of Sampling Sites for Chemical Analyses 56

Tables Page

1 Composition of Steel Wastes in Top Cover of Landfill 54

2 GC-MS Analyses of Polycyclic Aromatic Hydrocarbons (PAHs) in Core Samples 59

Tables Page

3 Electron Capture-Gas Chromatography Analyses of Polychlorinated Biphenyls (PCBs) in Core Samples 60

4 Quantitative GC-MS Analyses of Polycyclic Aromatic Hydrocarbons (PAHs) in Steel Wastes 62

References 64

A. INTRODUCTION

The contents of the landfill will never be known with any degree of certainty because there is no accurate or complete record of the types and amounts of wastes that were deposited. There is no doubt, however, that large volumes of potentially hazardous industrial liquid wastes were deposited at the site from the mid-1960s until January 1980, when the Hamilton-Wentworth Region prohibited the disposal of liquid wastes.

B. AMOUNT OF WASTES

During the 1960s and 1970s, city and regional workers kept traffic records of vehicles entering the site. It was estimated that, in 1965, approximately 8,000 vehicles a month, of which 20 per cent were cars, were transporting waste for disposal as compared to 18,328 vehicles in April 1978. A number of these vehicles were liquid waste tanker trucks. These records are not helpful in assessing the nature of wastes being landfilled but they do indicate a large and constant flow of waste materials to the site.

While the Upper Ottawa Street landfill was the site for disposal of many types of solid and liquid wastes, it is the industrial liquid wastes that are the greatest cause for concern. Prior to 1970, it would appear that a comparatively small volume of liquid wastes was being deposited at the site. Available records suggest that about 852,000 litres of liquid wastes were disposed of in 1970. Of this amount, the Region estimated that about 90 per cent originated locally from steel-related industries. The amount of liquid waste disposed of at the landfill increased rapidly during the 1970s, reaching an estimated 30-38 million litres in 1978. It is important to note that these amounts are based on a review of existing records, which are acknowledged to be incomplete and, therefore, may be underestimated.

The single most important reason for the increase in volume of wastes deposited at the landfill was the opening of a privately owned solidification/chemical fixation operation at the site in 1976. In 1975, an estimated 2.5 million litres of liquid wastes were sent to the landfill; this increased to approximately 15 million litres in 1976 and increased again in 1977 to about 24 million litres.

It was mentioned earlier that the solidification business also processed wastes from outside the Region and the province.(1) A United States Subcommittee on Oversight and Investigation, which is part of the House of Representatives Committee on Energy and Commerce, learned from a survey that a minimum of 5,800 tons of liquid wastes were sent to a processing plant in Hamilton by at least two large American chemical companies between 1975 and 1978, and these wastes were described as containing carbon tetrachloride and trichloroethene, along with numerous other components. According to the Ontario Ministry of the Environment's records, however, these wastes were not deposited as such but instead were processed for fuel and the water from this process was landfilled in the Upper Ottawa Street site.

Another reason for the dramatic increase in liquid waste disposal at the Upper Ottawa Street landfill in the mid-1970s was that other landfills in Hamilton and outside the Region had reached capacity and were being closed; consequently, industries and waste haulers were obliged to find alternative waste disposal sites. Since the closing of the Upper Ottawa Street landfill, there has been no liquid waste facility operating in the Hamilton-Wentworth Region.

While it is the industrial liquid wastes that are the greatest cause for concern, the possibility of hazardous chemical substances associated with domestic household garbage cannot be dismissed. Domestic garbage contains household products such as paint stripper and pesticides, as well as plastic materials containing plasticizers, which can accumulate to significant amounts in a landfill as large as the Upper Ottawa Street site. Additionally, decomposing household garbage may contain chemicals that are similar to some of those comprising liquid industrial wastes.

It is estimated that the landfill contains approximately 2.3 million cubic metres (i.e., 1.5 million tons of solid household and commercial garbage).(2) This is less than the amount of solid waste that was transported to the site because of the practice of burning solid garbage at the landfill, which was stopped in 1978, and accidental fires that occurred throughout the history of the site.

In addition to household and industrial garbage, it is estimated that at least 2.5 million tons of steel industry wastes were used in landfilling operations and as a final cover for the site.

C. DESCRIPTION OF WASTES

For many years the Hamilton-Wentworth Regional Laboratories analyzed samples of landfill leachate, water from the Red Hill Creek in the vicinity of the landfill, and materials from liquid waste tankers at the site. These analyses are useful in describing some general characteristics such as conductivity, metals content and alkalinity. The Regional Laboratories, however, were not equipped to do sophisticated organic analysis and, therefore, were not able to provide specific identification of most potentially toxic organic compounds.

From 1974 to 1980, the Regional Laboratories' analyses of various wastes sent to the landfill included the identification of compounds such as phenols, xylene, acetone, styrene and inorganics as well as the identification of substances, such as halogenated hydrocarbons and caustic solutions. The Regional Laboratories were also involved in deciding whether or not to permit companies to dispose of certain wastes at the Upper Ottawa Street landfill. At various times, the Region refused to allow the disposal of barrels of pesticides, naphthalenes and halogenated hydrocarbons. As these were the waste products of local industries, it might be expected that such wastes were at one time or another deposited at the landfill. Regional records also indicate the disposal by local industries of xylene, dichloromethane, trichloroethane and other halogenated hydrocarbons.

There is, of course, a great deal of anecdotal information from workers, waste haulers and area residents about the types of wastes that were landfilled. A former worker for a local waste company, which was the largest user of the landfill, alleged in newspaper interviews that from 1974 to 1977 he supervised the disposal of the following chemical wastes at the landfill: cyanide sludges, benzene, toluene, solvents, paint sludges, PCBs, xylene, isopropyl alcohol, methanol, acetone, hexane and vitavax.(3) This information is not verifiable, but it is interesting to note that most of these substances have been identified in the chemical analyses presented in this report.

Two attempts were made by local authorities to determine the types of wastes entering the landfill. In 1975, in addition to the analysis of waste materials by the Regional Laboratories, the Regional government made efforts to institute a liquid waste summary recording system. The description of the wastes required from waste haulers and waste generators was very broad (e.g., oily water, sludge) and not helpful in identifying the chemical nature of the waste materials. In 1979, the Region developed a list of wastes whose disposal at the landfill was prohibited. These wastes were halogenated hydrocarbons, PCBs, pesticides and herbicides, low flash point hydrocarbons, plating wastes and unfixed heavy metal solutions.

In 1977, the Ontario Ministry of the Environment implemented a waybill system, which was designed to identify the waste generator, the waste hauler, the amount and type of waste being transported and the disposal location. This system, however, was open to oversight and abuse. Lost records, uninformative descriptions of waste materials, and identification of the waste hauler, but not the waste generator, were among the problems encountered. In 1979, the format of waybills was revised to specify 21 separate categories of waste descriptions and the system was computerized.

D. STEEL WASTES

Beginning in 1976 steel industry wastes were used as fill for stabilizing the working face of the landfill.

The progressive slope or ramp method of landfilling was used at the Upper Ottawa Street site. This involved compacting wastes at a working area that was approximately 2.4 metres high and 15.2 metres long and covering the top portion of the area above this slope with steel industry wastes each day.

The amount of steel industry wastes placed on the Upper Ottawa Street landfill for this purpose from 1976 to 1980 is estimated to be approximately 2.2 million tons in total. The steel industry wastes were described as blended sludge, foundry sand, dust residues and sweepings from the rolling mill, slag processing and metal casting operations and air filtration systems.

The site was officially closed in October 1980 and from November 1980 to June 1981 a new use was found for steel wastes: approximately 340,000 tons of steel wastes were applied as a final cover.

A breakdown of the components of steel industry wastes used as a top cover on the landfill is shown below in Table 1.(4) The materials in this mixture are similar to those that were used as fill when the landfill was operating, with the exception that foundry sand was contained in steel industry wastes deposited in the site prior to 1981 while none was reported to be present in the top cover.

Table 1: **Composition of Steel Wastes in Top Cover of Landfill, 1981**

	Percentage
Blast Furnace Oxides	38.0
Steelmaking Oxides	37.0
Steelmaking Metallic Slag Fines	19.0
Hot Mill Filtration Plant Oxides	3.5
Cold Mill Water Treatment Plant Filter Cake	0.5
Excavated Clean Fill	0.5
Miscellaneous Sources Such As Roll Grindings, Lime Sludges, Tank Clean-outs and Floor Sweepings	1.5

E. CHEMICAL ANALYSES OF LANDFILL CONTENTS

E1. INTRODUCTION

In principle, it should be possible to determine analytically the chemicals present in the landfill. This would require, however, drilling hundreds of boreholes in the 27 metre high, 16 hectare site in order to sample buried wastes on a comprehensive basis. Even if this were done, one would not know with certainty if all toxic substances were being detected or if a toxic substance found in one or two locations is more widely dispersed in the landfill.

Nevertheless, advantage was taken of the fact that two replacement boreholes were drilled on the mound (near the former solidification lagoons and on the east end of the landfill - shown as Sites 6 and 16 in Figure 6 and described in Appendix 2) during the study. Chemical analyses were performed on six of the core samples at these sites taken from depths ranging from 7.6 metres to 24.4 metres.(5)

Analyses were also conducted on samples of materials obtained from the steel industry that were applied as a daily fill and a top cover on the landfill. The focus of these analyses was on the polycyclic aromatic hydrocarbons (PAHs), compounds that are formed during the combustion processes of steelmaking and some of which are known carcinogens.(6)

E2. CORE SAMPLES

E2.1 Analytical Methods

Mann Testing Laboratories conducted the organic analyses of core samples using capillary column gas chromatography-mass spectrometry (GC-MS). Gas chromatography separates the mixture of chemicals present in a sample, and the electron-impact mass spectrometer fragments some of the molecules and measures the M/Z ratios of the resulting ions as well as the M/Z ratio of the parent compound.*

The data thus obtained are stored in the computer and compared with spectra from the United States Environmental Protection Agency and the National Institute of Health computer library, which contains the mass spectra of 36,000 compounds. This computer then lists the three compounds which give the best match to each unknown compound and a numerical indication of how well the spectra match.

Because of the complex spectra of most organic compounds this computer matching process usually does not provide absolute identification. That would require matching of the observed spectra with that of a pure sample of the indicated compound using the same analytical instrument operating under identical conditions. Nevertheless, in the core sample analyses, the identity of many compounds, especially the aromatic hydrocarbons and the volatile chlorinated hydrocarbons, is strongly indicated.

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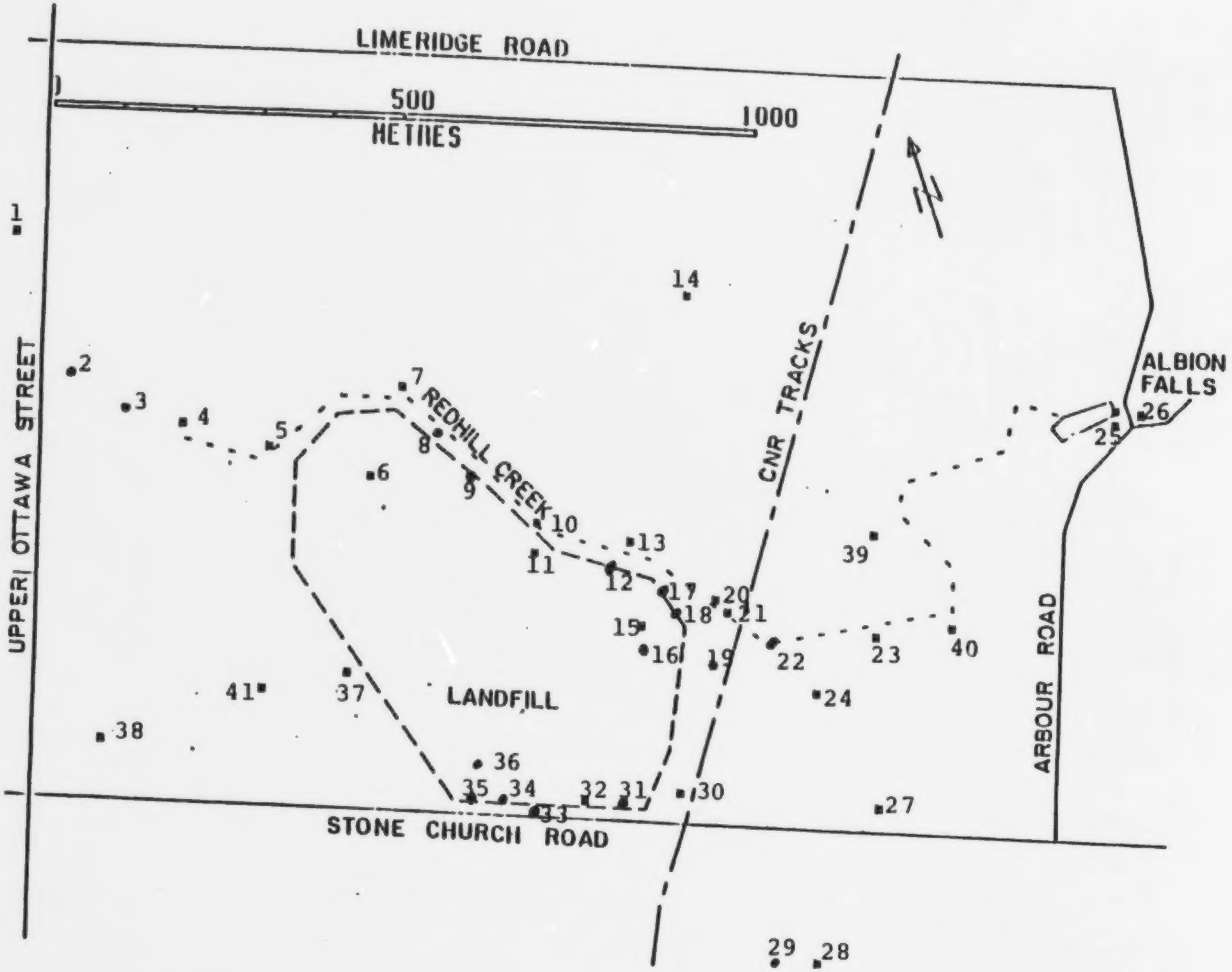
* These are the ratios of the mass (M) of the molecular ions to their electrical charge (Z).

FIGURE 6. Location of Sampling Sites for Chemical Analyses (See Appendix I for description of sampling locations.)


LIMERIDGE ROAD
0
500
1000
METRES
N
UPPER OTTAWA STREET
STONE CHURCH ROAD
ARBOUR ROAD
CNR TRACKS
REDHILL CREEK
LANDFILL
ALBION FALLS
1
2
3
4
5
6
7
8
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Three separation procedures were used to recover organics from core samples: heat treatment to remove volatile compounds, organic solvent extraction to remove basic and neutral compounds and aqueous alkali extraction to remove acidic compounds.* Each of the three groups of compounds was analyzed separately.

While the primary purpose of these analyses was to determine the identity of the organic constituents of the core samples, a semi-quantitative analysis was carried out for the polycyclic aromatic hydrocarbons (PAHs), some of which have carcinogenic properties. This involved the use of an internal standard, D-10 anthracene, whose mass spectrometer response (peak heights) was compared to the response for the individual PAHs in the sample being analyzed.**

In addition to the GC/MS analyses by Mann Testing Laboratories, a quantitative analysis for polychlorinated biphenyls was performed by Novalab Ltd. following Environment Canada's electron capture detection method.(7)

E2.2 Findings

The major volatile constituents of the core samples were the following:

- aliphatic hydrocarbons
- aromatic hydrocarbons
    - benzene
    - toluene
    - xylenes
    - C_3, C_4, and C_5 benzenes
    - naphthalene
- chlorinated hydrocarbons
    - dichloroethane
    - dichloroethene
    - trichloroethene
    - tetrachloroethene
- tetrahydrofuran

While these compounds were not quantified, inspection of the spectra showed that toluene was present in a concentration substantially larger than that of the chlorinated ethenes.

---

* The procedures used were patterned after EPA methods 624 and 625.

** Quantification was only approximate within an order of magnitude (i.e., a factor of ten) since the relationship between peak height and concentration is compound dependent.

The base neutral and acidic extracts were found to contain alkyl benzenes, polycyclic aromatic hydrocarbons (PAHs), phenols, substituted benzoic acids, and phthalates. In addition, there were present large quantities of petroleum-based hydrocarbons characteristic of waste oil.

The results of the semi-quantitative analysis of the PAHs are shown in Table 2. It can be seen that concentrations ranged from less than one to over thirty parts per million, with the higher concentrations being found at the greater depths. (Site 16)

The results of the polychlorinated biphenyls (PCBs) analysis of the core samples are presented in Table 3. These compounds were found in all samples at both Sites 6 and 16 in concentrations ranging from less than one part per million to 11 parts per million. As in the case of the PAH results, the higher concentrations of the PCBs were found at deeper levels within the garbage mound at Site 16. The electron capture detection method of analysis failed to detect chlorinated organics other than the PCBs.

E3. STEEL WASTES

E3.1 Analytical Methods

In May of 1981, the Ontario Ministry of the Environment performed GC-MS analyses on the organic compounds removed by soxhlet extraction from three samples of the steel industrial wastes that were utilized for the top cover. These analyses were not quantitative, and identification was tentative since pure standards were unavailable at the time.(8)

Late in the Committee's testing program, a quantitative analysis was carried out by Mann Testing Laboratories for targeted PAHs contained in the various types of steel wastes used either as daily fill or as final top cover. The organic compounds were removed from the solid wastes by solvent extraction, and deuterium-labelled PAHs were used as internal standards for the purpose of quantification .*(9)

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* Patterned after EPA Method 1625. Deuterium-labelled compounds are synthetic compounds in which hydrogen atoms in a molecule have been replaced by deuterium. Such compounds have a higher mass (i.e., molecular weight) than the corresponding unlabelled compound and, as a result, their spectra are displaced with respect to the spectra of their unlabelled counterpart. They may, therefore, be used as internal standards for direct comparison of peak heights. Since labelled compounds are expensive and have only recently become available, they were not used in the early stages of the Committee's testing program.

Table 2: GC-MS Analyses of PAHs in Core Samples[a]
parts per million

	Site 6				Site 16	
Sampling Depth	7.6m	13.7m	16.8m	19.8m	16.8m	24.4m
naphthalene	5.6	1.0	0.4	0.3	32.8	9.5
C_1-naphthalenes	0.8	0.2	0.1	0.1	4.2	3.9
C_2-naphthalenes	0.4	0.3	0.1	0.2	2.9	3.7
C_4-naphthalenes	0.3	0.2	0.1	0.0	0.2	1.4
biphenylene/acenaphthalene	0.7	0.2	0.1	0.2	1.0	0.3
phenalene/fluorene	0.7	0.4	0.1	0.0	3.7	1.7
phenanthrene	6.3	9.6	3.6	8.5	24.3	13.5
anthracene	0.6	0.9	0.5	0.7	5.6	1.2
C_1-anthracenes	0.4	0.5	0.2	0.3	2.5	1.4
C_2-anthracenes	0.3	0.4	0.1	0.1	1.3	0.9
C_3-anthracenes	0.2	0.2	0.1	0.1	0.8	0.3
fluoranthene	3.0	5.0	2.2	4.0	22.5	7.8
pyrene	4.5	6.3	2.5	6.2	23.5	9.0
methyl pyrene	0.1	0.4	0.1	0.2	3.0	0.6
C_2-pyrenes	0.1	0.1	0.0	0.0	0.5	0.1
C_3-pyrenes	0.1	0.1	0.1	0.1	1.4	0.2
chrysene	0.7	1.6	0.7	1.1	9.5	2.9
benzo (a) pyrene	0.6	2.0	1.1	1.5	7.3	2.4
benzo (g,h,i) perylene	0.1	0.3	0.2	0.2	0.6	0.4
1,2-dihydroacenaphthalene	0.8	0.4	0.2	0.4	2.0	0.7
dibenzofuran	0.9	0.2	0.1	0.3	2.4	1.0

Notes: Location of sampling sites shown in Figure 6.

[a] D-10 anthracene used as an internal standard. No correction was made for relative response; therefore, values reported are approximate concentrations. All analyses conducted by Mann Testing Laboratories.

Table 3: Electron Capture - Gas Chromatographic Analyses of Polychlorinated Biphenyls (PCBs) in Core Samples[a]
parts per million

	Site 6				Site 16	
Sampling depth	7.6m	13.7m	16.8m	19.8m	16.8m	24.4m
concentration	0.91	0.96	1.81	1.11	2.58	11.2

Notes: Location of sampling sites shown in Figure 6.

[a] Analyzed by Novalab Ltd. for Mann Testing Laboratories with quantification based on Aroclor 1242, 1254, and 1260 standards. Samples collected in August 1982.

In 1977 and again in 1980, the Hamilton-Wentworth Regional Laboratories carried out heavy metal, phenol, ammonia, nitrate and nitrite analyses on the steel wastes being deposited at the landfill. Samples of the material were mixed with two volumes of distilled water or slightly acidic water (pH 4.0) and the resulting leachate was analyzed by standard procedures.*(10)

E3.2 Findings

E3.2(a) Polycyclic Aromatic Hydrocarbons. The Ontario Ministry of the Environment identified four compounds as major PAH constituents of the steel wastes used as a top cover: anthracene, phenanthrene, pyrene and fluoranthene. In addition, many of the compounds listed in Table 2 were detected, as were methyl pyrene, acenaphthene, benzofluoranthene, benzoanthracene, methylbenzoanthracene and tetrahydro-4, 7-methano-1H-indene.(11)

The results of the quantitative analysis for targeted PAHs carried out for the Committee by Mann Testing Laboratories are shown in Table 4. It is possible that other non-targeted PAHs for which standards are unavailable were also present. For each targeted compound, there is a concentration below which quantification ceases to be reliable. These values are shown in Table 4 under the heading RQL (Reliable Quantification Limit) and targeted compounds detected at concentrations below their respective RQL are reported as BRQL (Below Reliable Quantification Limit).

It can be seen that significant amounts of PAHs are present, especially in the steelmaking oxides which constitute over a third of the material used as a cover.

The presence of PAHs in the ppm range in the steel waste cover materials is of concern only to the extent that there is the possibility for human exposure, either through air or water. Because these compounds, especially the more toxic ones, have a very low volatility, their concentration in gaseous form in the air can be expected to be extremely small. On the other hand, these compounds are readily adsorbed on fine dust particles (particulates) which on inhalation can become a serious health hazard. The potential for exposure by this route is examined in Chapter 8 dealing with chemicals in landfill gas and surrounding neighborhoods.

While the solubility of PAHs in water is very low, significant amounts may be present in the suspended material contained in landfill leachate. Settling of this material has the potential of producing high concentrations in the sediments deposited in the Red Hill Creek and the leachate collection manhole. Furthermore, since an extremely large amount of steel wastes is contained within the landfill and its top cover, even very slow leaching of PAHs may result over the years in the release of significant amounts of these chemicals. The PAH content of leachate and sediments is reported in Chapter 5.

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* Heavy metals were analyzed by atomic absorption spectrophotometric techniques. Phenols were analyzed colorimetrically using the 4-amino-anti-pyrine method.

Table 4: Quantitative GC-MS Analyses of PAHs in Steel Wastes[a]
parts per million

Steel Wastes	Blast Furnace Oxides	Steelmaking Oxides	Steelmaking Slag Fines	Filtration Plant Oxides	Cold Mill Filter Coke	Foundry Sands	RQL[c]
Composition of Top Cover	38%	37%	19%	3.5%	0.5%	(7-13%)[b]	
naphthalene	0.5	1.1	BRQL	0.5	0.8	0.1	0.1
2-methyl naphthalene	1.4	0.3	BRQL	0.7	3.3	0.1	0.1
dimethyl naphthalene	0.6	BRQL	ND	0.7	6.4	BRQL	0.2
trimethyl naphthalene	7.3	0.4	BRQL	1.0	ND	BRQL	0.1
acenaphthylene	BRQL	0.4	ND	ND	5.8	ND	0.1
acenaphthene	BRQL	0.4	ND	ND	1.0	ND	0.1
fluorene	ND	0.9	ND	0.1	1.4	BRQL	0.2
phenanthrene	2.1	13.3	0.3	1.9	5.4	0.9	0.2
methyl phenanthrene	5.7	1.7	0.4	6.8	ND	ND	0.2
anthracene	ND	ND	ND	ND	1.6	ND	0.2
methyl anthracene	ND	ND	ND	ND	0.9	ND	0.4
fluoranthene	4.8	33.3	BRQL	0.9	0.8	ND	0.4
pyrene	4.8	24.2	BRQL	0.7	1.1	ND	0.4
benzo(a)anthracene	ND	ND	BRQL	ND	1.1	ND	0.4
chrysene	2.0	24.3	BRQL	0.9	ND	ND	0.4
benzo(a)pyrene	ND	ND	ND	ND	ND	ND	0.6
benzo(e)pyrene	ND	ND	ND	ND	0.9	ND	0.6
benzo(b)fluoranthene	2.1	2.0	ND	ND	0.8	ND	0.6
benzo(k)fluoranthene	ND	ND	ND	ND	ND	ND	0.6
perylene	ND	ND	ND	ND	0.9	ND	0.6
benzo(g,h,i)perylene	ND	ND	ND	ND	ND	ND	1.0
indeno(1,2,3-cd)pyrene	ND	8.0	ND	BRQL	1.5	ND	1.0
dibenzo(a,h)anthracene	ND	3.2	ND	BRQL	1.5	ND	1.0
coronene	ND	BRQL	ND	ND	ND	ND	2.0
1H-phenalene	ND	ND	ND	ND	ND	ND	5.0
4h-cyclopenta(d,e,f)-phenanthrene	ND	ND	ND	ND	ND	ND	5.0

Notes:

[a] Isotopically labelled compounds were used as internal standards for identification and quantification. Analyses by Mann Testing Laboratories.

[b] Foundry sand was reported not to have been present in steel wastes used as top cover. Steel wastes used as daily cover from 1976-1980 contained 7-13% of this material.

[c] RQL means Reliable Quantification Limit of the analytical method.

BRQL means Detected but Below Reliable Quantification Limit.

ND means the compound was searched for; if present, the amount is below the detection limit.

E3.2(b) Heavy Metals. Leaching tests conducted by the Regional Laboratories yielded a leachate containing the heavy metals cadmium, copper, nickel, lead and zinc in maximum concentrations of one part per million. Chromium was not detected in these experiments.(12)

The pH of the leachate was in the range of 11 to 12. From this finding it may be concluded that the steel wastes are extremely alkaline and, under these conditions, the heavy metals would be mainly immobilized in the form of carbonates.

E3.2(c) Other. The Regional Laboratories' leaching tests gave solutions containing phenol in concentrations ranging from 15 parts per billion to 1.5 parts per million. Also, ammonium and nitrate ions were found in the parts per million and nitrite in the parts per billion range in this leachate.

References

1. Ontario, Ministry of the Environment, Status Report on an Industrial Liquid Waste Audit in Hamilton-Wentworth, 1978.

2. Conestoga-Rovers and Associates Limited, Feasibility Study on Landfill Gas Control at the Upper Ottawa Street Landfill, March 1983.

3. "I sent drums of poison sludge to landfill site," The Sunday Star, Toronto, October 5, 1980.

4. Upper Ottawa Street Landfill Site Study Committee, correspondence with Dofasco Inc., Hamilton, April 1982 and May 1985.

5. Mann Testing Laboratories Ltd., Chemical Analysis of Core Samples From Boreholes #2 and #4, October 1982.

6. Mann Testing Laboratories Ltd., Upper Ottawa Landfill Site Soil Analysis, August 16, 1985.

7. Novalab Ltd., Analysis of Water Samples for PCB, prepared for Mann Testing Laboratories Limited, June 14, 1982.

8. Ontario, Ministry of the Environment, correspondence of Laboratory Services Branch with Hamilton District Office, November 30, 1981.

9. Mann, Site Soil Analysis. (see reference 6)

10. Hamilton-Wentworth, Regional Municipal Laboratories, Analytical Laboratory Report, March 1977 and May 1980.

11. Ontario, Ministry of the Environment, correspondence of Laboratory Services Branch with Hamilton District Office, November 30, 1981.

12. Hamilton-Wentworth, Regional Municipal Laboratories, Analytical Laboratory Report, March 1977 and May 1980.

CHAPTER 5

CHEMICAL CONTENT OF LEACHATE, SURFACE WATERS AND SEDIMENTS

TABLE OF CONTENTS

Page

A. INTRODUCTION 70

B. WATER QUALITY PARAMETERS AND HEAVY METALS 71

  B1. METHODS 71

  B2. FINDINGS 71

    B2.1 Leachate 71
    B2.2 Surface Waters 72

C. ORGANIC POLLUTANTS 74

  C1. INTRODUCTION 74

  C2. METHODS 76

    C2.1 Gas Chromatography-Mass Spectrometry (GC-MS) 76

      C2.1(a) Qualitative Analysis 76
      C2.1(b) Quantitative Analysis (Mann Laboratories) 76
      C2.1(c) Semi-Quantitative Analysis (MOE and Stanford) 76

    C2.2 Electron Capture-Gas Chromatography (EC-GC) 76
    C2.3 Analysis for Dioxins 77

  C3. FINDINGS 77

    C3.1 Introduction 77
    C3.2 Analysis of Leachate 78

      C3.2(a) GC-MS Analysis of Leachate 78

Page

C3.2(b) GC-MS Quantitative Analysis of Leachate: General Organics 79
C3.2(c) GC-MS Quantitative Analysis of Leachate: Polycyclic Aromatic Hydrocarbons (PAHs) 81
C3.2(d) EC-GC Analyses of Leachate: Polychlorinated Biphenyls (PCBs) 81
C3.2(e) EC-GC Quantitative Analysis of Leachate: Chloro-Organic Pesticides 81
C3.2(f) Dioxins in Leachate 81

C3.3 ANALYSIS OF RED HILL CREEK WATERS 85

C3.3(a) GC-MS Survey Analysis of Red Hill Creek Waters 85
C3.3(b) GC-MS Quantitative Monitoring of Red Hill Creek: General Organics 85
C3.3(c) GC-MS Quantitative Analysis of Red Hill Creek Waters: Polycyclic Aromatic Hydrocarbons (PAHs) 85
C3.3(d) EC-GC Analysis of Red Hill Creek Waters: Polychlorinated Biphenyls (PCBs) 88
C3.3(e) EC-GC Analysis of Red Hill Creek Waters: Chloro-Organic Pesticides 88

C3.4 ANALYSIS OF CREEK AND LEACHATE SEDIMENTS 88

C3.4(a) GC-MS Survey Analysis of Red Hill Creek Sediments 88
C3.4(b) GC-MS Quantitative Analysis of Creek and Leachate Sediments: Polycyclic Aromatic Hydrocarbons (PAHs) 88
C3.4(c) EC-GC Analysis of Creek and Leachate Sediments: Polychlorinated Biphenyls (PCBs) 91

D. MUTAGENICITY ASSAYS 93

D1. INTRODUCTION 93

D2. METHODS 93

D3. FINDINGS 94

Tables | Page

5 Metals Analyses of Leachate 73

6 Metals Analyses of Surface Waters 75

7 GC-MS Analyses of Leachate 80

8 GC-MS Analyses of Polycyclic Aromatic Hydrocarbons (PAHs) in Leachate 82

9 EC-GC Analysis of Polychlorinated Biphenyls (PCBs) in Leachate 83

10 EC-GC Analyses of Leachate for Chloro-Organic Pesticides 84

11 GC-MS Monitoring of Surface Waters 86

12 Results of Polycyclic Aromatic Hydrocarbons (PAHs) in Surface Waters 87

13 EC-GC Analysis of Surface Waters for Chloro-Organic Pesticides 89

14 GC-MS Analysis of Sediments for Polycyclic Aromatic Hydrocarbons (PAHs) 90

15 EC-GC Analysis of Red Hill Creek and Leachate Sediments for Polychlorinated Biphenyls (PCBs) 92

References 95

APPENDIX 3

Table:

1 Water Quality and Inorganic Analyses of Leachate

2 Monitoring of Surface Waters for Water Quality and Inorganic Parameters

3 GC-MS Analyses of Leachate

4 Target Compounds Not Detected in GC-MS Analyses of Leachate

5 Additional Compounds in GC-MS Monitoring of Leachate Collection Manhole

6 GC-MS Monitoring of Surface Waters

7 Target Compounds Not Detected in GC-MS Monitoring of Surface Waters

A. INTRODUCTION

Leachate is the liquid formed by the percolation of precipitation through the wastes within the landfill. The composition of the leachate is determined by the chemicals present in the landfill and by their water solubility. In addition, however, leachate usually contains suspended solid materials in which compounds of low water solubility are present. Since leachate can be a significant source of human exposure to landfill chemicals, the determination of its composition is an important component of any landfill study.

At the Upper Ottawa Street landfill, and at many other sites in Ontario, an elevated groundwater mound exists in the landfill. The height of the mound is determined by the relative rates of infiltration of precipitation and flow of groundwater through the base of the site. Currently the mound at the Upper Ottawa Street site is approximately 7 metres above the surface of the ground. This height has not changed significantly since the application of the top cover, which would suggest that the amount of infiltration is still very significant.

Because of the mounded water table, leachate springs have developed on the slopes of the site. These are particularly noticeable on the north slope of the landfill at the base of a concrete withholding wall that was constructed to prevent erosion on this very steep north slope above the Red Hill Creek.

The chemical nature of the leachate from each spring can be expected to be characteristic of the landfill wastes in close proximity to the spring and, therefore, to vary widely among the sampling sites. For this reason, leachate samples were collected for analysis from a number of sites. These sites include a leachate collection manhole in which leachate from the south and east sides of the landfill is collected prior to being pumped into a sanitary sewer. The manhole leachate, while representative of a larger area of the landfill, may be diluted by surface runoff.

In addition to samples from the leachate springs and the collection manhole, leachate from several boreholes on the site itself were also collected and analyzed for their chemical content.

Since leachate from the springs on the north and northeast sides of the site enters the Red Hill Creek, this creek may be an important source of human exposure, especially downstream from the site itself. For this reason a regular monitoring program of the chemical content of the Red Hill Creek, both upstream and downstream of the landfill, was instituted.

Two groups of compounds are of particular concern in leachate samples, the polycyclic aromatic hydrocarbons (PAHs) and the polychlorinated biphenyls (PCBs). While these compounds have very low water solubility, they may be present in significant amounts in the suspended material contained in most leachates. Settling of this material during passage along the creek bed has the potential of producing high concentrations of these toxic compounds in the creek bottom sediments. Consequently, the focus of analysis of sediments was on these two classes of compounds.

In addition to the chemical analyses, mutagenicity assays were carried out on leachate and water samples from the Red Hill Creek. Such assays involve biological rather than chemical procedures. However, in order to present the findings of all work carried out on leachate and surface water in one part of the report, the mutagenicity results are presented in Section D of this Chapter.

The location of all sampling sites discussed in this chapter are shown in Figure 6 and described in detail in Appendix 2.

B. WATER QUALITY PARAMETERS AND HEAVY METALS

B1. METHODS

During the period 1976-80, which was prior to the commencement of this Study, leachate and surface water were monitored by the Ontario Ministry of the Environment for general water quality parameters (i.e. pH, conductivity, Biological Oxygen Demand, Chemical Oxygen Demand, chloride, nitrate, nitrite, ammonia, phosphate, etc.) and for heavy metals.(1) Additional analyses were carried out in 1982-84 by the MOE in support of the Waterloo Research Institute's groundwater investigation commissioned by the Study Committee.(2)

Standard methods of analysis were used by the MOE. For example, atomic absorption spectroscopy was employed for iron, manganese, arsenic and selenium; other heavy metals were analyzed by coupled plasma atomic emission spectroscopy.

B2. FINDINGS

B2.1 Leachate

In assessing the significance of these results, it is important to note that there is minimal current human exposure to leachate. A potential problem is migration of leachate from the site in surface and ground waters, even though there will be considerable dilution.

Detailed results of the measurements of water quality parameters and of heavy metal content are shown in Table 1 of Appendix 3 for leachate from three leachate springs (Sites 11, 17 and 35), two boreholes (Sites 6 and 15) and a former pool of leachate on the low side of the landfill referred to as the "blackhole" by area residents (Site 19). This pool was drained and covered in 1981 as part of the construction of the leachate collection system.

General water quality parameters are not particularly helpful in an investigation of the environmental and health impact of a landfill. Such analytic measurements are useful for assessing broad aspects of deteriorating water quality, but they provide no information on type and concentration of toxic substances of major concern in landfill studies. Not surprisingly, leachate is poor quality, well below acceptable drinking water criteria. Nitrogen in the form of ammonia is particularly high, a characteristic of leachate from decomposing domestic garbage.

Of more direct concern is the potential for human exposure to heavy metals, the toxicities of which have been fairly well documented. The results of the analyses of leachate samples for heavy metals are summarized in Table 5. For purposes of comparison, drinking water criteria are also tabulated.

The highest concentration of metals is found in the leachate from the borehole at Site 6. This is not surprising since this sampling location was the site of the solidification plant which processed millions of gallons of inorganic wastes from 1976 to 1980.

For most sites, the concentrations of aluminum and iron in leachate are relatively high. For other metals, however, concentrations from locations other than Site 6 are extremely low, often not greatly exceeding drinking water criteria. This is consistent with findings at other landfill sites where low metal migration is observed when metals have been co-disposed with domestic garbage.(3)

B2.2 Surface Waters

Monitoring of water quality parameters and heavy metals for Red Hill Creek was carried out over a two-year period by the Ontario Ministry of the Environment upstream (Site 2), downstream immediately below the landfill (Site 22) and further downstream at Albion Falls (Site 26).(4) Detailed results for measurements made during the summers of 1979, 1980 and 1981 are shown in Table 2 of Appendix 3.

While the general water quality of Red Hill Creek is poorer immediately downstream from the site, especially with respect to nitrogen-containing compounds, the effect of the landfill is not large. Furthermore, by the time the creek water has reached Albion Falls its overall quality is not greatly different from that of water upstream of the site which, surprisingly, comes close to meeting drinking water criteria in most parameters.

It is of interest to note that there was a significant improvement in general water quality by the summer of 1981. This follows the closure of the landfill, the construction of the leachate collection system and the installation of the top cover.

Table 5: Metal Analyses of Leachate
parts per million

	Site 6[a]	Site 11[b]	Site 15[b]	Site 17[c]	Site 19[d]	Site 35[e]	Drinking Water Criteria[f]
aluminum	1800			0.21	5.31	9.2	0.1
arsenic	0.04	0.01	0.03				0.05
cadmium	0.05	0.01	0.01	NR	0.02	0.01	0.005
chromium	17	0.04	0.82	0.01	0.30	0.26	0.05
copper	54	0.02	0.15	0.03	0.18	0.04	1.0
iron (total)	190	3.20	7.10	0.18	5.18	18.3	0.3
lead	43	0.03	0.10	0.01	0.34	0.19	0.05
manganese	NR	0.20	0.16	0.04	4.19	0.05	0.05
nickel	4.4	0.15	0.40	0.01	0.22	0.34	
zinc	100	0.03	0.47	0.05	0.55	0.54	5.0

Notes: Location of sampling sites shown in Figure 6.

[a] Analyzed by the Ontario Ministry of the Environment in 1980.
[b] Analyzed for the Waterloo Research Institute by the Ontario Ministry of the Environment in 1983.
[c] Sampled in July 1980 and analyzed by the Ontario Ministry of the Environment.
[d] Values reported are average of the three samples collected in 1979, 1980, and 1981 and analyzed by the Ontario Ministry of the Environment.
[e] Values reported are average of two samples taken in July 1980 and June 1981 and analyzed by the Ontario Ministry of the Environment.
[f] Ontario Ministry of the Environment Drinking Water Objectives (where available).

NR Means the presence or absence of the compound was not reported by the laboratory.

The results of the heavy metal analyses for surface waters are summarized in Table 6. It can be seen that concentrations are extremely low, rarely exceeding drinking water criteria and no higher downstream than upstream of the site. From this it can be concluded that heavy metals do not constitute a pollution problem for the Red Hill Creek.

C. ORGANIC POLLUTANTS

C1. INTRODUCTION

The main focus of attention in the chemical analyses of leachate, surface waters and Red Hill Creek sediments was directed to organic pollutants since these frequently constitute the greatest health hazard to an exposed population. In this work, the major analytical method was gas chromatography-mass spectrometry (GC-MS), which has become standard in the analysis of most organic compounds at the parts per billion level.

The majority of the GC-MS analyses were carried out by Mann Testing Laboratories under the direction of the Study Committee. Some additional leachate analyses were performed by the Ontario Ministry of the Environment and by Stanford University as part of the Waterloo Research Institute's groundwater investigation.

The general approach used in the GC-MS work by Mann Laboratories was, first, to carry out a comprehensive qualitative analysis using the EPA/NIH computer "library" for the matching of observed spectra with the spectra of known compounds (see page 55, Chapter 4). It is important to note that the analysis would have detected and identified the U.S. Environmental Protection Agency's priority pollutants.(5) Approximately one thousand compounds were detected. Numerous compounds were positively identified but many others were not identified. From this list, approximately 130 were targeted for further quantification work. The selection of compounds for the quantification list was based on toxicological assessment, reliability of identification and frequency of occurrence.

In addition to the general analysis for organic compounds by GC-MS, other analytical methods were used for specific compounds. Polychlorinated biphenyls (PCBs) and chloro-organic pesticides were analyzed for using electron capture-gas chromatography methods. Dioxin was analyzed for using a TAGA 6000 double mass spectrometer.

Table 6: **Metals Analyses of Surface Waters**
parts per million

	Site 19 (Blackhole)			Site 2 (Upstream)			Site 22 (Downstream)			Drinking Water Criteria[a]
	July '79	July '80	June '81	July '79	Apr. '80	July '81	July '79	July '80	July '81	
aluminum	9.7	5.9	0.34	0.26	2.0	0.75	0.09	0.18	0.47	0.1
arsenic	NR	NR	NR	NR	0.002	NR	NR	0.001	NR	0.05
cadmium	0.05	0.02	0.001	0.005	0.005	0.001	0.005	0.007	0.001	0.005
chromium	0.55	0.34	0.006	0.02	0.02	0.007	0.02	0.003	0.006	0.05
copper	0.4	0.13	0.02	0.01	0.01	0.01	0.01	0.02	0.01	1.0
iron(total)	7.0	8.2	0.33	2.9	2.9	0.82	0.22	0.23	0.50	0.3
lead	0.30	0.72	0.01	0.03	0.03	0.01	0.03	0.03	0.03	0.05
manganese	12	0.48	0.09	0.04	NR	0.07	0.05	0.08	0.06	0.05
nickel	0.35	0.30	0.01	0.02	0.02	0.07	0.02	0.01	0.01	
zinc	1.2	0.38	0.08	0.09	0.11	0.15	0.01	0.07	0.07	5.0

Notes: Location of sampling sites shown in Figure 6.

All samples analyzed by the Ontario Ministry of the Environment.

[a] Ontario Ministry of the Environment Drinking Water Objectives (where available).

NR Means the presence or absence of the compound was not reported by the laboratory.

C2. METHODS

C2.1 Gas Chromatography-Mass Spectrometry (GC-MS)

C2.1(a) Qualitative Analysis. Using EPA methods 624 and 625, three groups of compounds, volatile, base-neutral and acidic, were recovered from water and sediment samples and were analyzed separately by computer matching of spectra with the spectra in the EPA/NIH library. For each compound detected, the computer lists the three compounds in the library giving the best match and provides a numerical value for the degree of matching.(6)

C2.1(b) Quantitative Analysis (Mann Laboratories). Two approaches were used for the quantitative GC-MS work.(7,8) In the first (EPA method 624 for volatile compounds and 625 for extractables) pure samples of each of the compounds being quantified (targeted compounds) were used as external standards. This provided a calibration for each compound from which mass spectrometer peak area response could be converted into actual amounts (e.g. ppm, ppb, etc.).

The second approach (EPA method 1624 for volatiles and 1625 for extractables) employed deuterium-labelled analogs of each of the targeted compounds as internal standards . While the use of labelled compounds is the preferred method of analysis, these compounds are expensive and are often unavailable for the pollutants of interest.

Each quantitative analysis was accompanied by a computer scan of observed spectra and was matched with the EPA/NIH library. This permitted the detection, without quantification, of compounds not on the targeted list.

C2.1(c) Semi-Quantitative Analysis (MOE and Stanford). A simplified procedure providing an approximate quantification (within a factor of ten) of identified compounds was employed by the Ontario Ministry of the Environment and Stanford University in their leachate and groundwater analyses for the Waterloo Research Institute.(9) This involved the use of an appropriate single compound or a mixture of compounds (unlabelled) as internal standards. Quantification is approximate since the relationship between peak area and concentration is compound dependent.

C2.2 Electron Capture-Gas Chromatography (EC-GC)

An electron capture-gas chromatographic technique (EPA method 608) was used by MOE (10) and Novalab Ltd. (11) for the analysis of polychlorinated biphenyls (PCBs)* and chloro-organic pesticides. The electron capture detector is selectively sensitive to chlorinated compounds. The method is based on the matching of the total peak heights present in the gas chromatographic "fingerprints" of the leachate samples and a PCB standard.

C2.3 Analysis for Dioxins

Samples of leachate were analyzed for dioxin by the Health Protection Branch of Health and Welfare Canada, Ottawa using the TAGA 6000 double mass spectrometer developed by Sciex (see page 154 in Chapter 8).(12) The instrument was programmed to target specifically for dioxin within a detection limit of one part per trillion. Leachate was also analyzed for dioxin by Mann Laboratories using GC-MS techniques within a detection limit of five parts per trillion.(13)

C3. FINDINGS

C3.1 Introduction

The results of the analyses for organic compounds present in, or originating from, leachate are presented under three main headings: leachate, Red Hill Creek water and Red Hill Creek bottom sediments.** The last are of interest in that sediments may contain compounds such as PAHs and PCBs, which have low water solubility but may be adsorbed on suspended solid material in leachate.

Because of the very large amount of GC-MS data resulting from organic analyses, either carried out for the Study Committee or commissioned by consultants to the Committee, the main body of this Report presents only those results which, in the Committee's judgement, may be of significance in relation to possible health and environmental effects. Tables 3, 4, 5, 6 and 7 of Appendix 3 provide a more complete presentation of the general GC-MS organic results.

Special importance is attached to the presence of PAHs in water and sediments because of the deposition in the site of steel wastes. For this reason a full report on the analysis of these compounds is presented in the main body of the Report. The results of the PCB analyses are treated similarly because of the high level of public concern associated with these compounds.

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* PCBs are sold under the trade name Aroclor. Aroclors are complex mixtures of chlorinated biphenyls differing in the degree of chlorination. Since only a few PCBs are available as pure compounds, analysts tend to rely on such mixtures, variously designated as Aroclor 1016, 1242, 1254, etc., as standards.

** Groundwater chemistry is presented in Chapter 7 in the context of the hydrogeology of the region and the direction of flow of the contaminated groundwater plume discussed in Chapter 6.

C3.2 Analysis of Leachate

C3.2(a) GC-MS Survey Analysis of Leachate. A qualitative survey was made in 1981-82 by Mann Testing Laboratories for organics in leachate sampled from seven locations: a leachate spring on the north side of the landfill below the former solidification lagoon (Site 9); a former pool on the low-lying east side of the site which residents called the "blackhole" (Site 19); an open drainage ditch on the southwest side of the landfill (Site 34); a culvert on the east side of the landfill near the blackhole, and three boreholes on the landfill (Sites 6, 16, and 36).(14)

The following is an overview of the results of the survey analysis of organic compounds in leachate samples:

*aliphatic hydrocarbons Many compounds characteristic of petroleum products were observed at all sites. There seems little doubt that the landfill was a repository for waste oils of one kind or another during its operation.

alkyl benzenes Benzene, toluene, xylenes, and a number of isomeric C_3- and C_4- alkyl benzenes were observed in the blackhole leachate and occasionally at other leachate sites.

polycyclic aromatic hydrocarbons Other than napthalene, azulene, and anthracene in the blackhole leachate, PAHs were not observed in water samples. This is in contrast to sediment samples, which were found to contain a large number of these highly toxic compounds. (See page 88 of this chapter.)

chlorinated hydrocarbons Dichloromethane, chloroform, 1,2-dichloroethene, trichloroethene, and 1,4-dichlorobenzene were found in the blackhole leachate but usually not at other sites.

*carboxylic acids Acids detected include C_4 to C_{10} aliphatic acids, alkyl-substituted benzoic acids, phthalic acid, benzene acetic acid and benzene propionic acid.

esters Several of phthalate esters were detected and were probably mainly present as plasticizers in the plastic materials contained in domestic garbage.

alcohols A few alcohols were tentatively identified, as was butyl cellusolve, which is widely used as an industrial solvent.

aldehydes and ketones In addition to acetone and methyl ethyl ketone (2-butanone), some higher molecular ketones and aldehydes were tentatively identified.

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* These compounds are not toxic at low concentrations and, therefore, they were not included in the subsequent quantification work.

heterocyclic compounds The two most frequently observed compounds were tetrahydrofuran and 1,4-dioxane. Other heterocyclic compounds tentatively identified include indole, carbazole, benzothiazolone, and isoquinoline.

C3.2(b) GC-MS Quantitative Analysis of Leachate: General Organics. Analyses for targeted compounds were made by Mann Testing Laboratories leachate from five locations: four leachate springs on the north slope of the landfill (Sites 3, 9, 12, and 18) and the leachate from the leachate collection manhole (Site 32).(15, 16) In addition, semi-quantitative approaches to measurements of organic pollutants in leachate were carried out for the Waterloo Research Institute by the Ontario Ministry of the Environment (onsite boreholes at Site 15) and Stanford University (leachate spring at Site 11).(17) These semi-quantitative analyses are accurate within a factor of ten. (see Section C2.1(c) of this chapter.)

The main findings of these analyses are summarized in Table 7. (See Table 3 of Appendix 3 for more detailed reports.) For each targeted compound, there is a concentration below which quantification ceases to be reliable. These values are shown in the table under the heading Reliable Quantification Limit (RQL), and targeted compounds detected at concentrations below their respective RQL are reported as Below Reliable Quantification Limit (BRQL). Table 7 also includes for most compounds, values for acceptable drinking water standards or objectives. These help to place into some perspective observed values for the concentration of pollutants.

It can be seen that the greatest number of compounds in the highest concentrations were found in the leachate collection manhole (Site 32). High concentrations were found in the onsite borehole leachate (Site 15) and in one leachate spring (Site 11). These values, however, are less reliable because analyses did not involve the use of targeted standards.

Concentrations of pollutants in the remaining leachate springs (Sites 3, 9, 12, and 18) were relatively low, with the exception of the plasticizer bis(2-ethylhexyl)-phthalate, tetrahydrofuran and 1,4-dioxane. The last two compounds were seen in high concentrations at all sites, suggesting that significant quantities are widely dispersed within the landfill. It is of interest to note that these compounds have only rarely been observed at landfill sites in the United States.(18)

The so-called blackhole was closed before the Study Committee's quantification program was initiated. The MOE, however, did undertake a semi-quantitative analysis of volatile organics in leachate from this source in 1979.(19) None of the compounds detected, with the exception of ethylbenzene at 147 ppb, exceeded the concentrations reported in Table 7.

As would be expected, the concentrations of organic pollutants in leachate samples generally exceed drinking water standards. Nevertheless, the results would seem to indicate that the landfill site was not the repository of large amounts of concentrated organic chemical wastes. In this respect, it differs from

Table 7: GC-MS Analyses of Leachate
parts per billion

	Site 3[a]	Site 9[a]	Site 11[b]	Site 12[a]	Site 15[c]	Site 18[a]	Site 32[d]	RQL[e]	Drinking Water Criteria[f,g]
benzene	1.9	1.1	0.6	2.8	7.2	9.1	3.6	1.0	1.0[g]
toluene	BRQL	BRQL	1.3	BRQL	229	12.1	30.4	1.0	50.0[g]
xylenes	14.7	BRQL	164	63.7	332	50.0	142	1.0	50.0[g]
ethylbenzene	1.1	ND	24.1	ND	74.0	14.2	9.2	1.0	50.0[g]
C_3-benzenes	3.0	BRQL	1,396	BRQL	275	18.2	15.8	1.0	50.0[g]
C_4-benzenes	2.1	2.6	D	19.3	212	5.0	5.2	1.0	
dichloromethane	19.7	BRQL	4.8	BRQL	ND	BRQL	21,800	5.0	50.0[g]
dichlorobenzenes	BRQL	BRQL	21.3	24.4	ND	BRQL	11.8	1.0	20.0[g]
di-n-butyl phthalate	3.9	5.2	85.6	10.3	ND	23.4	2.5	0.4	50.0[g]
bis(2-ethylhexyl)phthlate	240	201	ND	147	350	147	360	0.9	4.0[g]
phenol	ND	ND	12.3	ND	92	105	98.1	3.0	2.0[f]
cresols	ND	ND	ND	ND	134	9.1	25.7	3.0	2.0[f]
xylenols	ND	BRQL	40.8	BRQL	576	36.4	10.5	2.0	2.0[f]
aniline	ND	ND	72.8	ND	ND	ND	15.0		1.0[g]
tetrahydrofuran	1,043	18.5	D	343	23.9	330	3,700	1.0	50.0[g]
1,4-dioxane	2,610	103	D	1,951	26.6	4,926	18,663	80	
benzothiazole	ND	ND	24.5	BRQL	D	ND	ND	0.8	

Notes: Location of sampling sites shown in Figure 6.

[a] Analyzed by Mann Testing Laboratories.
[b] Analyzed by Stanford University.
[c] Analyzed by the Ontario Ministry of the Environment.
[d] Samples from leachate collection manhole collected in July 1983, March, October and December 1984, and analyzed by Mann Testing Laboratories. Highest values reported. (Target compound analysis)
[e] RQL means Reliable Quantification Limit of the analytical method.
[f] Ontario Ministry of the Environment Drinking Water Objectives (where available).
[g] New York State Proposed Drinking Water Toxic Standards, January 1985 (where available).

D means the compound is detected but the amount not determined.
BRQL means detected but Below Reliable Quantification Limit
ND means the compound was searched for; if present, the amount is below the detection limit.

the situation at Love Canal. It must be kept in mind, however, that the leachate samples analyzed may not be entirely representative of all materials contained in the landfill.

C3.2(c) GC-MS Quantitative Analysis of Leachate: Polycyclic Aromatic Hydrocarbons (PAHs). The results of the PAH analyses of leachate using GC-MS are shown in Table 8.(20, 21, 22) Sampling sites are the same as those used for the general organic analysis reported in the preceding section. Again, the highest concentrations were found in the leachate collection manhole. In general, however, few compounds were detected and, where detected, amounts were low, even in relation to drinking water standards. Many more compounds at much higher concentrations were found in sediments. (see page 88 in this chapter)

C3.2(d) EC-GC Analyses of Leachate: Polychlorinated Biphenyls (PCBs). The results of PCB analyses of leachate using EC-GC are shown in Table 9.(23,24,25,26) Three of the sampling sites were onsite boreholes: Site 6 at a depth of 22.5 metres, Site 16 at 32 metres, and Site 36 at shallow depth. A fourth, Site 32, was the leachate collection manhole. The highest concentrations were found in two of the boreholes, 48 ppb in the leachate from Site 16 and 19 ppb in a thick, black, oily liquid taken from Site 36.* Concentrations in the leachate collection manhole were also significant, up to 3.1 ppb.

Analyses by the MOE in the summer of 1980, before the commencement of this Committee's work, showed PCB concentrations of 0.2 parts per billion in the 'blackhole' (Site 19) and 0.6 parts per billion in a leachate spring (Site 35).(27)

C3.2(e) EC-GC Quantitative Analysis of Leachate: Chloro-Organic Pesticides. The results of EC-GC analyses of chloro-organic pesticides in leachate from four leachate springs on the north slope (Sites 3, 9, 12, and 18) and the leachate collection manhole (Site 32) are presented in Table 10.(28,29) It can be seen that most of the common chlorine-containing pesticides could not be detected, and the four that were found, gamma BHC, heptachlor, aldrin, and 4,4'-DDE, were present in concentrations below a RQL of 0.1 ppb.

C3.2(f) Dioxins in Leachate. No dioxins or the related polychlorinated benzofurans were found at the detection limit of one part per trillion in two samples taken from the leachate collection manhole (Site 32) (30) nor from a subsequent analysis of one sample from the same site at a higher detection limit of 5 parts per trillion.(31)

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*Mann Laboratories reported 68 ppb of PCBs in leachate from an onsite borehole, Site 15, using GC-MS techniques (in Appendix 3, Table 3). No standard was used in this measurement.

Table 8: GC-MS Analyses of Polycyclic Aromatic Hydrocarbons (PAHs) in Leachate
parts per billion

	Site 3[a]	Site 9[a]	Site 11[b]	Site 12[a]	Site 15[c]	Site 18[a]	Site 32[d]	RQL[e]	Drinking Water Criteria [f]
naphthalene [g]	BRQL	BRQL	382	BRQL	D	28.5	11.8	0.4	10.0
methylnaphthalenes [g]	BRQL	BRQL	77.2	BRQL	ND	3.5	BRQL	0.5	
1,2-dimethylnaphthalene [g]	BRQL	ND	ND	BRQL	ND	6.2	BRQL	0.6	
acenaphthylene [g]	ND	ND	ND	ND	ND	ND	BRQL	0.5	
acenaphthene [g]	0.5	ND	8.1	1.9	24	2.5	1.3	0.4	20.0
9H-fluorene [g]	1.6	ND	ND	5.3	ND	2.1	ND	0.4	50.0
phenanthrene [g]	0.8	BRQL	ND	5.5	26	2.9	3.8	0.3	50.0
methylphenanthrene	NR	NR	ND	NR	154	NR	ND		
anthracene [g]	ND	ND	ND	12.8	ND	3.9	19.8	0.3	50.0
2-methylanthracene [g]	BRQL	ND	ND	BRQL	ND	1.4	BRQL	0.8	
fluoranthene [g]	BRQL	BRQL	2.6	1.8	260	BRQL	112.5	0.6	50.0
pyrene [g]	BRQL	BRQL	ND	1.9	19	BRQL	118	0.5	50.0
benzo(a)anthracene [g]	ND	ND	ND	ND	ND	ND	24.0	0.5	0.002
chrysene [g]	ND	ND	ND	ND	ND	ND	24.0	0.4	0.002
benzo(a)pyrene [g]	ND	ND	ND	ND	ND	ND	BRQL	0.3	0.002
benzo(b)fluoranthene [g]	ND	ND	ND	ND	ND	ND	BRQL	0.6	0.002
benzo(k)fluoranthene [g]	ND	ND	ND	ND	ND	ND	BRQL	0.4	0.002
perylene [g]	ND	ND	ND	ND	ND	ND	ND	2.5	
benzo(g,h,i)perylene [g]	ND	ND	ND	ND	ND	ND	BRQL	2.0	
indeno(1,2,3-cd)pyrene [g]	ND	ND	ND	ND	ND	ND	BRQL	1.3	0.002
dibenzo(a,h)anthracene [g]	ND	ND	ND	ND	ND	ND	BRQL	4.0	
coronene [g]	ND	ND	ND	ND	ND	ND	ND	2.5	
1H-phenalene	NR	NR	ND	NR	140	NR	ND		
4h-cyclopenta(d,e,f)-phenanthrene	NR	NR	ND	NR	17	NR	NR		

Notes: Location of sampling sites are shown in Figure 6.

[a] Analyzed by Mann Testing Laboratories
[b] Analyzed by Stanford University.
[c] Analyzed by the Ontario Ministry of the Environment.
[d] Samples from leachate collection manhole collected in July 1983, March, October and December 1984, and analyzed by Mann Testing Laboratories. Highest values reported here.
[e] RQL means Reliable Quantification Limit of the analytical method.
[f] New York State Proposed Drinking Water Toxics Standards, January 1985 (where available).
[g] Target compound analysis of Sites 3, 9, 12, 18 and 32.

D means the compound is detected but the amount not determined.
BRQL means detected but Below Reliable Quantification Limit
ND means the compound was searched for; if present, the amount is below the detection limit.

Table 9: Electron Capture-Gas Chromatographic Analyses of Polychlorinated Biphenyls (PCBs) in Leachate
parts per billion

Sampling Date	Site 6	Site 16	Site 32	Site 36
April, 1980[a]	ND	NR	NR	NR
Sept., 1981[b]	NR	NR	NR	19.3
Nov., 1981[c]	ND	ND	2.1	NR
May, 1982[b]	0.15	48.0	NR	NR
June, 1982[c]	ND	ND	3.0	NR
Nov., 1983[c]	ND	ND	ND	NR
Mar., Oct., and Dec. 1984[d]	NR	NR	ND	NR

Notes: Location of sampling sites shown in Figure 6.

[a] Analyzed by the Ontario Ministry of the Environment.
[b] Analyzed for Mann Testing Laboratories by Novalab Ltd. with quantification based on Aroclor 1254 standard.
[c] Analyzed for Gartner Lee Associates by the Ontario Research Foundation with quantification based on Aroclor 1254 and 1260 standards.
[d] Analyzed by Mann Testing Laboratories, with quantification based on Aroclor 1242, 1254 and 1260 standards.

ND means the compound was searched for; if present, the amount is below the detection limit.
NR means the presence or absence of the compound was not reported by the laboratory.

Table 10: Electron Capture-Gas Chromatographic Analyses of Leachate for Chloro-Organic Pesticides[a]
parts per billion

	Site 3	Site 9	Site 12	Site 18	Site 32
alpha BHC	ND	ND	ND	ND	NR
gamma BHC	BRQL	ND	ND	ND	ND
beta BHC	ND	ND	ND	ND	ND
delta BHC	ND	ND	ND	ND	ND
fluchloralin	ND	ND	ND	ND	ND
heptachlor	BRQL	ND	ND	ND	ND
aldrin	ND	ND	ND	BRQL	ND
heptachlor epoxide	ND	ND	ND	ND	ND
oxychlordane	ND	ND	ND	ND	ND
alpha endosulfan	ND	ND	ND	ND	ND
beta endosulfan	ND	ND	ND	ND	ND
4,4'-DDD	ND	ND	ND	ND	ND
4,4'-DDT	ND	ND	ND	ND	NR
mirex	ND	ND	ND	ND	ND
4,4'-DDE	BRQL	ND	ND	ND	ND
dieldrin	ND	ND	ND	ND	ND
endrin	ND	ND	ND	ND	ND
endrin aldehyde	ND	ND	ND	ND	ND
endosulfan sulfate	ND	ND	ND	ND	ND

Notes: Location of sampling sites shown in Figure 6.

[a] All analyses conducted by Mann Testing Laboratories on samples collected in June 1984.

BRQL means detected but Below the Reliable Quantification Limit of 0.1 ppb.
ND means the compound was searched for; if present, the amount is below the detection limit.
NR means the presence or absence of the compound was not reported by the laboratory.

C3.3 Analysis of Red Hill Creek Waters

C3.3(a) GC-MS Survey Analysis of Red Hill Creek Waters. A qualitative survey of organics in the Red Hill Creek was made in 1981-82 by Mann Testing Laboratories at two sampling sites: upstream of the landfill just below the culvert at Ottawa Street (Site 2) and downstream of the landfill immediately below the railway track bridge (Site 22).(32) As expected, many fewer compounds were detected than in the analysis of leachate samples. Also, there were no striking differences in the chemical content of upstream and downstream samples.

C3.3(b) GC-MS Quantitative Monitoring of Red Hill Creek: General Organics. Upstream and downstream water samples from Red Hill Creek were analyzed for organic pollutants in July 1983 and March, October and December of 1984 by Mann Testing Laboratories using as standards for quantification either pure samples of targeted compounds or their deuterated-labelled analogs.(33) The main findings are summarized in Table 11, and a more detailed report is found in Table 6 of Appendix 3. For purposes of comparison, these tables also report the results of the analysis of leachate from the collection manhole (Site 32), sampled at the same time as the Red Hill Creek waters. *

It can be seen that many fewer compounds and much lower concentrations were found in the Red Hill Creek samples than in the collection manhole leachate. This is to be expected because of dilution effects. Of greater significance is the observation that with the exception of phenol, cresols, xylenols, tetrahydrofuran, and 1,4-dioxane, the concentration of organic pollutants was not significantly higher in downstream than in upstream samples. Also, few compounds were found in concentrations in excess of drinking water standards where these have been established. Notable exceptions are phenols, cresols, xylenols, and bis(2-ethyl hexyl) phthalates. While the last compound, a plasticizer, is clearly present in the landfill, the major source of this pollutant would appear to be upstream from the site. Finally, there is some indication that the amount of contamination is decreasing with time.

In summary the Red Hill Creek is much less polluted by organic chemicals than might have been expected from its proximity to the landfill. In fact, much of the pollution in the creek comes from sources upstream from the site.

C3.3(c) GC-MS Quantitative Analysis of Red Hill Creek Waters: Polycyclic Aromatic Hydrocarbons (PAHs). The results of the PAH analyses of upstream and downstream Red Hill Creek waters and of leachate from the collection manhole are reported in Table 12.(34) Sampling sites and times were the same as those in Table 11.

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* The results reported in Table 11 for the collection manhole leachate sampled in July 1983 (first column) were reported earlier in Table 7, section C3.2(b) and in Appendix 3, Table 3.

Table 11: GC-MS Monitoring of Surface Waters[a]
parts per billion

	Site 32 (Leachate Collection Manhole)				Site 2 (Upstream)				Site 22 (Downstream)				RQL[f]	Drinking Water Criteria[g,h]
	1[b]	2[c]	3[d]	4[e]	1	2	3	4	1	2	3	4		
benzene	3.6	ND	BRQL	BRQL	BRQL	ND	ND	ND	BRQL	ND	ND	ND	1.0	1.0[h]
toluene	30.4	BRQL	2.6	3.5	BRQL	ND	ND	ND	BRQL	ND	ND	ND	1.0	50.0[h]
xylenes	142	ND	13.5	49.3	ND	ND	BRQL	ND	BRQL	ND	ND	ND	1.0	50.0[h]
ethylbenzene	9.2	ND	ND	ND	ND	ND	ND	ND	BRQL	ND	ND	ND	1.0	50.0[h]
trimethylbenzenes	15.8	ND	1.0	5.4	ND	ND	ND	ND	ND	ND	ND	ND	1.0	50.0[h]
tetramethylbenzenes	5.2	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.0	
dichloromethane	222	18.8	21,800	11,700	BRQL	31.5	BRQL	ND	15.2	31.8	ND	BRQL	5.0	50.0[h]
dichlorobenzenes	11.8	7.7	3.9	3.3	BRQL	BRQL	BRQL	ND	BRQL	BRQL	BRQL	ND	1.0	20.0[h]
di-n-butyl phthalate	NR	BRQL	ND	2.5	NR	ND	BRQL	1.2	NR	ND	ND	1.2	0.4	
bis(2-ethylhexyl) phthalate	13.1	360	17.6	51.6	24.3	24.8	6.0	13.2	21.2	92.0	7.2	7.1	0.9	4.0[h]
phenol	98.1	BRQL	BRQL	BRQL	BRQL	ND	ND	ND	70.2	ND	ND	1.5	1.5	2.0[g]
cresols	25.7	ND	ND	ND	ND	ND	ND	ND	11.1	ND	ND	ND	3.0	2.0[g]
xylenols	10.5	7.4	BRQL	BRQL	ND	BRQL	ND	ND	5.6	BRQL	BRQL	ND	2.0	2.0[g]
aniline	15.0	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND		1.0[h]
tetrahydrofuran	1,213	1,549	2,457	3,700	BRQL	ND	ND	ND	1.4	ND	4.5	2.7	1.0	50.0[h]
1,4-dioxane	18,663	949	6,745	16,700	ND	ND	ND	ND	ND	ND	68.4	ND	80.0	

Notes: Location of sampling sites shown in Figure 6.

[a] All analyses by Mann Testing Laboratories.(Target compound analysis)
[b] Sampled in July, 1983.
[c] Sampled in March, 1984.
[d] Sampled in October, 1984.
[e] Sampled in December, 1984.
[f] RQL means Reliable Quantification Limit of the analytical method.
[g] Ontario Ministry of the Environment Drinking Water Objectives (where available).
[h] New York State Proposed Drinking Water Toxics Standards, January 1985 (where available).

BRQL means Detected but Below Reliable Quantification Limit
ND means the compound was searched for; if present, the amount is below the detection limit.
NR means the presence or absence of the compound was not reported by the laboratory.

Table 12: Results of GC-MS Analyses of Polycyclic Aromatic Hydrocarbons (PAHs) in Surface Waters
parts per billion

	Site 32 (Leachate Collection Manhole)				Site 2 (Upstream)				Site 22 (Downstream)				RQL[f]	Drinking Water Criteria[g]
	1[b]	2[c]	3[d]	4[e]	1	2	3	4	1	2	3	4		
naphthalene	11.8	BRQL	BRQL	BRQL	ND	BRQL	2.9	ND	ND	3.2	BRQL	ND	0.4	10.0
methylnaphthalenes	BRQL	ND	BRQL	BRQL	ND	2.2	BRQL	ND	ND	5.5	ND	ND	0.5	
1,2-dimethylnaphthalene	BRQL	ND	BRQL	ND	ND	15.6	ND	ND	ND	10.0	ND	ND	0.6	
acenaphthylene	ND	BRQL	BRQL	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.5	
acenaphthene	NR	1.1	1.3	ND	NR	ND	1.7	ND	NR	ND	0.7	ND	0.4	20.0
9H-fluorene	NR	ND	ND	ND	NR	2.0	1.4	ND	NR	BRQL	1.8	ND	0.4	
phenanthrene	NR	ND	2.5	3.8	NR	0.6	1.2	BRQL	NR	0.8	ND	BRQL	0.3	50.0
anthracene	19.8	ND	BRQL	ND	ND	ND	ND	ND	ND	BRQL	ND	ND	0.3	50.0
2-methylanthracene	ND	ND	BRQL	ND	ND	BRQL	ND	ND	ND	BRQL	ND	ND	0.8	
fluoranthene	10.6	0.5	BRQL	112.5	ND	BRQL	BRQL	BRQL	ND	BRQL	BRQL	ND	0.4	50.0
pyrene	10.5	BRQL	BRQL	118.0	ND	BRQL	BRQL	BRQL	ND	BRQL	BRQL	BRQL	0.5	50.0
benzo(a)anthracene	3.1	BRQL	BRQL	24.0	ND	ND	BRQL	BRQL	ND	ND	ND	BRQL	0.5	0.002
chrysene	NR	BRQL	BRQL	24.0	NR	ND	BRQL	BRQL	NR	ND	ND	BRQL	0.4	0.002
benzo(a)pyrene	NR	BRQL	ND	BRQL	NR	ND	BRQL	BRQL	NR	ND	ND	BRQL	0.3	0.002
benzo(b)fluoranthene	ND	ND	ND	BRQL	ND	ND	ND	BRQL	ND	ND	ND	BRQL	0.6	0.002
benzo(k)fluoranthene	NR	BRQL	ND	BRQL	NR	ND	ND	BRQL	NR	ND	ND	BRQL	0.4	0.002
perylene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.5	
benzo(g,h,i)perylene	NR	BRQL	ND	BRQL	NR	ND	ND	BRQL	NR	ND	ND	BRQL	2.0	
indeno(1,2,3,-cd)pyrene	NR	ND	ND	BRQL	NR	ND	ND	BRQL	NR	ND	ND	BRQL	1.3	0.002
dibenzo(a,h)anthracene	NR	BRQL	ND	BRQL	NR	ND	ND	BRQL	NR	ND	ND	BRQL	4.0	
coronene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.5	

Notes: Location of sampling sites shown in Figure 6.

[a] All analyses by Mann Testing Laboratories. (Target compound analysis)
[b] Sampled in July 1983.
[c] Sampled in March, 1984.
[d] Sampled in October, 1984.
[e] Sampled in December , 1984.
[f] RQL means Reliable Quantification Limit of the analytical method.
[g] New York State proposed Drinking Water Toxics Standards, January 1985 (where available).

BRQL means Detected but amount is Below Reliable Quantification Limit.
ND means the compound was searched for; if present, the amount is below the detection limit.
NR means the presence or absence of the compound was not reported by the laboratory.

Few differences were observed between upstream and downstream water samples. Also, in most cases, quantities were below the reliable quantification limit (RQL). It should be noted, however, that in these analyses the RQL values were considerably higher than the drinking water criteria for some of the more potent carcinogens.

C3.3(d) EC-GC Analysis of Red Hill Creek Waters: Polychlorinated Biphenyls (PCBs). Polychlorinated biphenyls were detected in upstream and downstream Red Hill Creek water samples by the Ministry of the Environment in amounts below the quantification limit of 0.02 parts per trillion.(35) None was found by MOE in an earlier analysis in 1980 (36) or by Novalab Ltd. in 1981 (37) and the Mann Testing Laboratories in 1983 and 1984.(38) These results are not surprising in view of the low solubility of these compounds in water. The PCBs present in the leachate suspensions are more likely to appear in the Red Hill Creek sediments.

These findings may be compared to PCB concentrations ranging from 0.02 ppb to 1.2 ppb found in 1975 for leachate from a number of landfills in southern Ontario.(39)

C3.3(e) EC-GC Analysis of Red Hill Creek Waters: Chloro-Organic Pesticides. The results reported in Table 13 show that no chloro-organic pesticides were detected immediately downstream of the landfill (Site 22).(40,41) Trace amounts of alpha BHC and gamma chlordane were found upstream (Site 2), and trace amounts of HCB, 4,4'-DDE and 4,4'-DDD were found at Albion Falls (Site 26).

C3.4 Analysis of Creek and Leachate Sediments

C3.4(a) GC-MS Survey Analysis of Red Hill Creek Sediments. A qualitative survey of organics in Red Hill Creek sediments upstream and downstream of the landfill (Sites 2 and 22) was carried out by Mann Testing Laboratories at the same time as the survey of the Red Hill Creek waters.(42)

The major downstream pollutants tentatively identified were polycyclic aromatic hydrocarbons, the detergent tetramethylbutyl phenol (tyloxapol), and the heterocyclic compounds, dibenzofuran, 4-methyldibenzofuran, dibenzothiophene and 9H-carbazole. Phthalates were found in both upstream and downstream sediments.

C3.4(b) GC-MS Quantitative Analysis of Creek and Leachate Sediments: Polycyclic Aromatic Hydrocarbons (PAHs). The results of the GC-MS quantitative analysis of sediments for PAHs using labelled compounds as standards are shown in Table 14.(43) Sampling sites were upstream to the landfill (Site 2); downstream (Site 22); at a shallow water site at the base of the retaining apron where leachate is flowing into the Creek (Site 8); just above the Creek water level at a leachate spring on the north slope of the landfill (Site 12); and a leachate collection ditch on the south side (Site 31). Concentrations of detected compounds in these sediments, which are shown in ppm, are very much higher than the ppb

Table 13: **Electron Capture-Gas Chromatographic Analyses of Surface Waters for Chloro-Organic Pesticides**
parts per billion

	Site 2[a] (Upstream)	Site 22[a] (Downstream)	Site 32[a] (Collection Manhole)	Site 26[b] (Albion Falls)	RQL[c]
HCB	ND	ND	NR	0.02	0.001
alpha BHC	0.001	ND	ND	ND	0.010
beta BHC	ND	ND	ND	ND	0.010
gamma BHC (Lindane)	ND	ND	ND	ND	0.010
delta BHC	ND	ND	ND	NR	0.010
heptachlor	ND	ND	ND	ND	0.010
aldrin	ND	ND	ND	ND	0.010
heptachlor epoxide	ND	ND	ND	ND	0.010
alpha endosulfan	ND	ND	ND	ND	0.010
beta endosulfan	ND	ND	ND	ND	0.010
4,4'-DDE	ND	ND	ND	0.01	0.010
dieldrin	ND	ND	ND	ND	0.010
endrin	ND	ND	ND	ND	0.010
andrin aldehyde	ND	ND	ND	NR	0.010
endosulfan sulfate	ND	ND	ND	NR	0.010
4,4'-DDD	ND	ND	ND	0.01	0.010
2,4'-DDT	ND	ND	NR	ND	0.005
4,4'-DDT	ND	ND	ND	ND	0.010
alpha chlordane	ND	ND	NR	ND	0.001
gamma chlordane	0.001	ND	NR	ND	0.001
mirex	ND	ND	ND	ND	0.050
toxaphene	ND	ND	ND	NR	0.200

Notes: Location of sampling sites are shown in Figure 6.

[a] Analyzed by Mann Testing Laboratories on samples collected in March, October and December, 1984.

[b] Analyzed by the Ontario Ministry of the Environment on samples collected in April 1980.

[c] RQL means Reliable Quantification Limit of the analytical method.

ND means the compound was searched for; if present, the amount is below the detection limit.
NR means the presence or absence of the compound was not reported by the laboratory.

Table 14: GC-MS Analyses of Sediments for Polycyclic Aromatic Hydrocarbons (PAHs)[a]
parts per million

	Site 2 (Red Hill Creek Upstream)	Site 22 (Red Hill Creek Downstream)	Site 8 (Base of North Slope)	Site 12 (Base of North Slope)	Site 31 (South Ditch)	RQL[b]
naphthalene	BRQL	BRQL	BRQL	0.3	BRQL	0.1
2-methyl naphthalene	ND	ND	ND	ND	ND	0.1
dimethyl naphthalene	ND	ND	ND	BRQL	ND	0.2
trimethyl naphthalene	BRQL	ND	ND	ND	ND	0.1
acenaphthylene	ND	ND	ND	ND	ND	0.1
acenaphthene	ND	ND	ND	ND	ND	0.1
fluorene	ND	ND	ND	BRQL	ND	0.2
phenanthrene	2.0	0.8	0.5	1.0	BRQL	0.2
methyl phenanthrene	2.8	10.8	1.7	6.4	13.5	0.2
anthracene	ND	ND	ND	ND	ND	0.2
methyl anthracene	ND	ND	ND	ND	ND	0.4
fluoranthene	4.4	1.4	1.0	BRQL	BRQL	0.4
pyrene	3.6	1.1	0.9	BRQL	BRQL	0.4
benzo(a)anthracene	ND	ND	ND	ND	ND	0.4
chrysene	2.1	BRQL	BRQL	BRQL	BRQL	0.4
benzo(a)pyrene	ND	ND	ND	ND	ND	0.6
benzo(e)pyrene	ND	ND	ND	ND	ND	0.6
benzo(b)fluoranthene	2.7	1.0	BRQL	BRQL	BRQL	0.6
benzo(k)fluoranthene	ND	ND	ND	ND	ND	0.6
perylene	ND	ND	ND	ND	ND	0.6
benzo(g,h,i)perylene	ND	ND	ND	ND	ND	1.0
indeno(1,2,3-cd)pyrene	BRQL	BRQL	BRQL	ND	ND	1.0
dibenzo(a,h)anthracene	BRQL	BRQL	BRQL	ND	ND	1.0
coronene	BRQL	ND	ND	ND	ND	2.0
1H-phenalene	ND	ND	ND	ND	ND	5.0
4h-cyclopenta(d,e,f,) phenanthrene	ND	ND	ND	ND	ND	5.0

Notes: Location of sampling sites shown in Figure 6.

[a] All analyses by Mann Testing Laboratories in June 1985. (Target compound analysis)
[b] RQL means Reliable Quantification Limit of the analytical method.

BRQL means Detected but Below Reliable Quantification Limit.
ND means the compound was searched for; if present, the amount is below the detection limit.

levels found in leachate and in Red Hill Creek waters (Tables 8 and 12). This is consistent with the very low solubility of these compounds in water. In fact, the few PAHs that were found in the water samples were probably adsorbed on suspended particles since samples were not filtered prior to analysis.

It is seen that in general PAH concentrations in sediments were somewhat higher upstream of the landfill than downstream or at the several leachate sites. The exception to this is found in the case of methyl phenanthrene for which upstream and downstream concentrations were 2.8 and 10.9 ppm, respectively. (The sediment collected in the south ditch - Site 31 - contained 13.6 ppm of this compound.) It may be noted that PAH concentrations have been shown to be present in river sediments in the range of 0.2 to 1.8 ppm and in marine sediments in 0.04 to 0.4 ppm.(44)

While the list of PAHs targeted for analysis in this Study is like that of similar studies, it should be recognised that other PAHs may also be present. Recent research has indicated that alkyl substituted polycylic aromatic hydrocarbons, for which very few standards are yet available, are present in some types of steel wastes and that they represent a significant group of environmental carcinogens.(45)

C3.4(c) EC-GC Analysis of Creek and Leachate Sediments: Polychlorinated Biphenyls (PCBs). The results of the electron capture-gas chromatographic analyses of sediments for PCBs are shown in Table 15.(46) Sampling sites were from the Red Hill Creek upstream (Site 2), downstream (Site 22), at Albion Falls (Site 26), the base of the retaining apron where leachate flows into the Creek (Site 9), a leachate spring at the base of the north slope (Site 12) and the leachate collection ditch on the south side (Site 31).

It can be seen that PCBs are more prevalent and generally in higher concentrations in sediments than in leachate (compare with Table 9). Furthermore, concentrations are higher immediately downstream from the landfill than upstream or further downstream at Albion Falls*. Significant concentrations are also found in leachate sediments sampled at the base of the north and south slopes of the landfill.

While there is little doubt that the landfill is contributing PCBs to the creek, it cannot be the only source. In 1980, the Ontario Ministry of the Environment

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* In 1979, Gartner Lee reported that Peninsula Chemical Analysis Ltd. found very high PCB values of 662,000 ppb in upstream sediments and 244,000 ppb in downstream sediments. The same samples were subsequently analyzed by the Ontario Research Foundation at the request of the Hamilton-Wentworth Regional Laboratories and were reported to contain concentrations of 60 ppb upstream and 150 ppb downstream. The Regional Laboratories concluded that the Peninsula results were in error. The findings shown in Table 15 support this conclusion.

Table 15: Electron Capture-Gas Chromatographic Analysis of Polychlorinated Biphenyls (PCBs) in Red Hill Creek and Leachate Sediments
parts per billion

Sampling date	Site 2 (Red Hill Creek Upstream)	Site 22 (Red Hill Creek Downstream)	Site 26 (Albion Falls)	Site 9 (Base of North Slope)	Site 12 (Base of North Slope)	Site 31 (South Ditch)
October, 1979[a]	140	NR	70	NR	NR	NR
October, 1980[b]	60	150	NR	NR	NR	NR
November, 1980[c]	390	900	17	NR	NR	NR
September, 1981[d]	90	70	NR	NR	NR	NR
June, 1982[e]	24	NR	25	NR	NR	NR
November, 1983[e]	18	NR	34	NR	NR	NR
May, 1985[f]	60	100	NR	280	570	540

Notes: Location of sampling sites shown in Figure 6.

[a] Analyzed by the Ontario Ministry of the Environment.
[b] Analyzed by the Ontario Research Foundation with quantification based on Aroclor 1254 and 1260 standards.
[c] Analyzed by Beak Laboratories for Gartner-Lee Associates.
[d] Analyzed by Novalab Ltd. for Mann Testing Laboratories with quantification based on Aroclor 1260 standard.
[e] Analyzed by the Ontario Research Foundation for Gartner-Lee Associates with quantification based on Aroclor 1254 and 1260 standards.
[f] Analyzed by Mann Testing Laboratories with quantification based on Aroclor 1242 and 1260 standards.

NR means the presence or absence of the compound was not reported by the laboratory.

found PCBs in a concentration of 200 ppb in a sediment sample at Site 3, which is at the mouth of a discharge channel extending from the Public Works yard to the west of the landfill, and in a concentration of 900 ppb in soil around an oil storage tank in that yard.(47)

The PCB concentrations found in the creek sediments, ranging from 18 to 900 ppb, can be compared to 1,300 ppb reported for sediments in the canal region of Hamilton harbour, 2,000 to 3,000 ppb in the industrial waterfront region and 10,000 ppb near the sewage treatment plant.(48)

D. MUTAGENICITY ASSAYS

D1. INTRODUCTION

A procedure known as the Ames assay was used to determine whether or not mutagenic substances are present in leachate and water from the Red Hill Creek. Since most carcinogens are mutagens and most non-carcinogens are non-mutagenic, mutagenic testing provides a preliminary indication of the presence or absence of carcinogens. The Ames assay is not infallible, however, since there are compounds, some in common everyday use, which are not carcinogenic but give a positive result in an Ames assay. Furthermore, the assay itself does not measure quantitatively the cancer potency of a substance, nor does it provide an estimate of health risk to humans.

D2. METHODS

The Ames assay is a simple, rapid, widely used and relatively inexpensive test that shows whether a chemical or a mixture of chemicals causes mutation in certain carefully constructed strains of bacteria.* The testing was carried out by

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*The bacteria employed in this assay are unable to synthesize an essential amino acid called histidine and, as a result, grow only when this substance is supplied in the culture medium. Mutations can occur in individual bacteria that restore the ability of that cell to make histidine and to grow and form a colony that is visible to the naked eye. Mutagenic chemicals increase the rate of mutation and thus increase the number of colonies on the test plates. A test is generally considered to be positive if (1) there are a least twice as many colonies (revertants) on the test plates as on the background controls and (2) the number of revertants increases with the dose of the material being assayed. Different strains (e.g., TA98, TA100) which respond to different types of mutagens are needed to give comprehensive coverage.

Mutatech Inc. on samples collected from five sites as well as on a sample of Hamilton tap water for comparison. Leachate was collected from two groundwater boreholes, shown as Sites 6 and 16 in Figure 5, and the leachate collection manhole at Site 32. Red Hill Creek water samples were collected upstream of the landfill at Site 2 and downstream at Site 22. Five strains of bacteria (TA98, TA100, TA1535, TA15237 and TA1538) were employed in the assays and the procedures were those described by Ames et. al. in 1975 and Salamone et. al. in 1979.

D3. FINDINGS

The results show that only in the case of leachate from one borehole (Site 16) was a clear doubling of the background number of revertants obtained (with strain TA98), indicating unequivocally the presence of mutagens. Two other samples from a borehole (Site 6) and the Red Hill Creek downstream (Site 22) showed indications that mutagenic material might be present but failed to produce a doubling of the background reversion rate which is the accepted criterion for a positive dose response.(49)

The results show that some samples of leachate contain mutagenic chemicals. The levels, however, are low and near the limits of detection of the Ames assay. Given that the presence of polynuclear aromatic hydrocarbons (PAHs) in leachate was already known, this finding was not unexpected.

References

1. Frank Crossley, The Effects of the Upper Ottawa Street Landfill Site on Groundwater and Surface Water, February, 1982.

2. J.A. Cherry, J.F. Barker, R.J. Blackport and J.E. Barbash, Hydrogeological Investigations of the Upper Ottawa Street Landfill Site in Hamilton, (Ontario) (Final Report), Institute of Groundwater Research at the University of Waterloo, October, 1984.

3. F.G. Pohland, J.P. Gould, R.E. Ramsey, D.C. and Walters, "The Behaviour of Heavy Metals During Landfill Disposal of Hazardous Wastes," in Land Disposal of Hazardous Wastes: Proceedings of the Eighth Annual Research Symposium, ed. David W. Schultz (U.S. Environmental Protection Agency: Publication No. 600/9-82-002), March, 1982), 360-371.

4. Crossley, Effects of Landfill on Water. (see reference 1)

5. Mann Testing Laboratories Ltd., Reports of Chemical Characterization by GC-MS Spectrometry, May and August, 1982.

6. Ibid.

7. Mann Testing Laboratories Ltd., Analysis of 4 Leachate Samples, prepared for the Upper Ottawa Street Landfill Site Study Committee, October 18, 1984.

8. Mann Testing Laboratories Ltd., Monitoring of Leachate and Red Hill Creek at the Upper Ottawa Street Landfill Site: Reports 1-4. September, 1982. October, 1984. January and March, 1985.

9. Cherry, Barker, Blackport and Barbash, Hydrogeological Investigations (Final Report).

10. Crossley, Effects of Landfill on Water. (see reference 1)

11. Mann, Reports of Chemical Characterization. (see reference 5)

12. J.J. Ryan, Correspondence "re. Analysis of Two Leachate Samples for Dioxins and Furans," prepared for the Upper Ottawa Street Landfill Site Study Committee by the Health Protection Branch, Health and Welfare Canada, May 11, 1983.

13. Mann Testing Laboratories Ltd., Report No. 3 on Monitoring Red Hill Creek and Leachate at the Upper Ottawa Street Landfill Site, January, 1985.

14. Mann, Reports of Chemical Characterization. (see reference 5)

15. Mann, Analysis of 4 Leachate samples. (see reference 7)

16. Mann, Monitoring of Leachate and Red Hill Creek. (see reference 8)

17. Cherry, Barker, Blackport and Barbash, Hydrogeological Investigations (Final Report). (see reference 2)

18. Universities Associated For Research and Education in Pathology, Inc., Health Aspects of the Disposal of Waste Chemicals, Draft of a Final Report to be published in the spring of 1986 by Pergamon Press Inc., Elmsford, New York.

19. Ontario, Ministry of the Environment, Report of the Laboratory Services Branch, April 1979.

20. Cherry, Barker, Blackport and Barbash, Hydrogeological Investigations (Final Report). (see reference 2)

21. Mann, Analysis of 4 Leachate Samples. (see reference 7)

22. Mann, Monitoring of Leachate and Red Hill Creek. (see reference 8)

23. Crossley, Effects of Landfill on Water. (see reference 1)

24. Mann, Reports of Chemical Characterization. (see reference 5)

25. Mann, Monitoring of Leachate and Red Hill Creek. (see reference 8)

26. Gartner-Lee Associates Limited, Hydrogeological Study of Leachate and Gas Impacts (Stage 2) at the Upper Ottawa Street Landfill, Hamilton-Wentworth, September, 1980.

27. Ibid.

28. Mann, Analysis of 4 Leachate Samples. (see reference 7)

29. Mann, Monitoring of Leachate and Red Hill Creek. (see reference 8)

30. J.J. Ryan, "Analysis of Two Leachate Samples." (see reference 12)

31. Mann, Report No. 3 on Red Hill Creek and Leachate. (see reference 8)

32. Mann, Reports of Chemical Characterization. (see reference 5)

33. Mann, Monitoring of Leachate and Red Hill Creek. (see reference 8)

34. Ibid.

35. Crossley, Effects of Landfill on Water. (see reference 1)

36. Ibid.

37. Mann, Reports of Chemical Characterization. (see reference 5)

38. Mann, Monitoring of Leachate and Red Hill Creek. (see reference 8)

39. A report of the Task Force on PCBs to the Environmental Contaminants Committee of Environment Canada and Health and Welfare Canada, Technical Report 76-1. April, 1976.

40. Crossley, Effects of Landfill on Water. (see reference 1)

41. Mann, Monitoring of Leachate and Red Hill Creek. (see reference 8)

42. Mann, Reports of Chemical Characterization. (see reference 5)

43. Mann Testing Laboratories Ltd., Upper Ottawa Street Landfill Site Soil Analysis, August 16, 1985.

44. Ontario, Ministry of the Environment, Hazardous Contaminants Programme; Polynuclear Aromatic Hydrocarbons -- A Background Report Including Available Ontario Data (ARB-TDA-Report No. 58-79), September 1979.

45. M.A. Quilliam, M.S. Lant, C. Kaiser-Farrell, D. McCalla, C.P. Sheldrake, A.A. Kerr, J.N. Lockington and E.S. Gibson, "Indentification of Polycyclic Aromatic Compounds in Mutagenic Emissions From Steel Casting, Biomedical Mass Spectrometry, 12:4 (1985), 143-150.

46. Mann, Soil Analysis (see reference 43)

47. Gartner Lee, Hydrogeological Study (Stage 2). (see reference 26)

48. The Hamilton Harbour values were the highest documented in Canada by 1976. They can be compared to sediments found in Georgian Bay near Collingwood (20 ppb) and in the centre of Lake Superior (90 pbb). See reference 12.

49. Mutatech Inc., Report on the Analysis of Air Particulates and Leachate From the Upper Ottawa Street Landfill for Mutagenicity in Ames Tests, November 1982.

CHAPTER 6

THE DIRECTION AND RATE OF FLOW OF GROUNDWATER

TABLE OF CONTENTS

Page

A. INTRODUCTION 100

B. FIELD METHODS 102

C. GEOLOGICAL SETTING 102

D. CHARACTERISTICS OF GROUNDWATER FLOW 106

D1. HYDRAULIC CONDUCTIVITY 107
D2. HYDRAULIC GRADIENTS 108

D2.1 Horizontal Gradient 108
D2.2 Vertical Gradient 110

E. LEACHATE PRODUCTION 112

F. VELOCITY OF GROUNDWATER FLOW 114

Figures Page

7 Location of the University of Waterloo Research Institute Sampling Points and Piezometers 103

8 Regional Geological Setting of the Landfill 104

9 Schematic Vertical Geological Sections 105

10 Water Table Map 109

11 Vertical Cross Section Showing Hydraulic Head 111

References 116

A. INTRODUCTION

Contamination of the groundwater by landfill pollutants was immediately identified as a critical component of the Study Committee's overall research program. The Ontario Ministry of the Environment confirmed that no household wells in the area were being used; therefore, it was unlikely that human exposure to contaminated drinking water existed. The Study Committee was concerned, however, that persons might be exposed through recreational use to landfill contaminated groundwater and leachate seeps flowing into the Red Hill Creek and into the pond and waterfall located in the Albion Falls conservation area. In addition to the potential problem of contaminated groundwater discharging into surface waters, groundwater might be flowing in many directions and at unpredictable rates, because the landfill is sitting on fractured bedrock. This might result in a discharge through the surface of the ground at distances away from the site. The landfill is located about one kilometre from the edge of the Niagara escarpment at Albion Falls. It is possible, therefore, that the flow of contaminated groundwater could eventually break out through the face of the escarpment. The Study Committee knew that in research undertaken at other landfill sites, organic compounds had been detected in groundwater. It was necessary, therefore, to determine whether a similar situation exists at the Upper Ottawa Street Landfill site.

The concern that a potentially serious problem might be associated with landfill contamination of groundwater was supported to some extent by the findings of exploratory hydrogeological work conducted for the Region in 1978-1979 by Gartner Lee Associates Limited.(1) The results of this study showed that the landfill site is sitting on fractured bedrock, a groundwater mound exists within the landfill, and leachate is being produced. The findings indicated the general direction of groundwater flow to be primarily east, but also to the south. Analyses of groundwater samples for water quality parameters suggested organic contamination, and the results of inorganic analyses indicated the presence of relatively low concentrations of metals. An organic chloride pesticide scan indicated the presence of trace levels of pesticides in two boreholes, while no PCBs were detected in any of the groundwater samples tested. Gartner Lee Associates concluded that as the groundwater flows away from the landfill, the concentration of contaminants decreases, likely as a result of dilution and dispersion.

While the Gartner Lee Associates work provided very useful preliminary information on hydrogeological aspects of the landfill, it was not designed to obtain the detailed information the Study Committee believed was necessary for a full assessment of the problem of groundwater contamination, particularly in light of the complex fractured rock setting. The direction of the groundwater flow was not well defined and very limited information was available on the rates of angular flow through more or less horizontal and vertical fissures and cracks. This was a function of the limited nature of Gartner Lee Associates work, which involved drilling eleven boreholes, each of which measured only two levels of groundwater. Of particular concern to the Study Committee was the general omission of organic chemical analyses. The concern about toxicity is much greater for organic compounds than for either inorganic compounds or general water quality parameters.

It was decided to commission a comprehensive study of the hydrogeological impact of landfill contamination on groundwater. The terms of reference for this study defined the need to obtain information on the rates and direction of both horizontal and vertical groundwater flows; the delineation and characterization of the contaminated groundwater plume, including the analyses of organic compounds; and the trend in concentration of compounds as groundwater flows away from the landfill. The Study Committee retained the services of the University of Waterloo Research Institute (WRI), under the direction of Dr. John Cherry, to conduct this investigation.

Most hydrogeological research relating to landfill problems has been devoted to the behaviour of groundwater in sand and clay. Very little work has been conducted on fractured bedrock because it is difficult to determine groundwater movement in rock that contains numerous, tiny fractures as well as large cracks and fissures that are distributed in pathways throughout the rock. The conventional instrument used by hydrogeologists to study groundwater flow is a piezometer installed in a drilled borehole, which measures a groundwater level at one depth only. This is satisfactory for studies in uniform sand or clay in which a limited number of piezometers at different depths provide sufficent data to delineate the direction and rate of groundwater flow. In fractured bedrock, however, the widely varying characteristics of the fractures require many times the normal number of piezometers to obtain adequate information.

It was clear to the Study Committee's groundwater consultants that to install the very large number of individual piezometers needed to characterize groundwater flow at many depths over the large area surrounding the Upper Ottawa Street landfill site was impractical. Therefore, the first stage of the Waterloo Research Institute's study was to develop a new monitoring device that would permit the measurement of groundwater flow at a number of depths in a single borehole.(2) The consultants were successful in designing and fieldtesting a new multilevel monitoring device that can be used at an average of five depths in a single borehole. The WRI began installing the new multilevel device as part of the major groundwater study at the Upper Ottawa Street landfill in the spring of 1982. The design of the device was improved as the investigation proceeded and these new monitoring devices have since been used by hydrogeologists in four other field studies elsewhere in Ontario and for a study in New Brunswick.

B. FIELD METHODS

The Waterloo Research Institute's plan for the groundwater investigation consisted of two parts: physical hydrogeology and groundwater chemistry. The purpose of the physical groundwater study was to describe the geology, hydraulic conductivity and hydraulic gradient in the fractured bedrock and to use this information to predict the direction and rate of flow of groundwater away from the landfill. The purpose of the groundwater chemistry work (see Chapter 7) was to identify and quantify the chemicals in this groundwater and to use that information to map any contaminated groundwater plume.

Boreholes were drilled at 26 locations around the landfill to depths ranging from 25 to 50 metres. The multilevel devices were installed in each of the boreholes, including a borehole that was drilled at a 45° angle under the landfill. The latter permitted the sampling of groundwaters directly beneath the site where concentrations of contaminants might be expected to be highest. The new multilevel devices generally contained five separate piezometers for sampling at five separate depths in each borehole.

The location of the WRI boreholes is shown in Figure 7. Many of these boreholes are also shown as sampling sites (with different numbers) in Figure 6 and are described in detail in Appendix 2. Eight boreholes are situated to the north and west of the landfill; six are on the landfill or along Red Hill Creek to the north; twelve are to the east and north of the site, and one borehole is considerably south of the landfill. Each time a borehole was drilled, a continuous rock core was collected and examined for fractures; information about the pattern of fractures was used to decide the vertical location of piezometers to be used for monitoring water levels and chemical sampling.

C. GEOLOGICAL SETTING

The classification of the natural characteristics of the rock is a starting point for hydrologeological investigations of the type undertaken by WRI.

Figure 8 depicts the major rock formations under the landfill with reference to Albion Falls, the City of Hamilton below the escarpment, and Lake Ontario. It is clear from this diagram that landfill contaminated groundwater can reach the face of the escarpment at Albion Falls through the three upper levels of rock but must migrate vertically into the Queenston shale formation if it is to flow under the base of the escarpment towards Lake Ontario.

In Figure 9, the regional rock units depicted in Figure 8 (above the Queenston shale), are described in more detail with respect to the rock type and geological formation or member.

FIGURE 7: Location of the University of Waterloo Research Institute sampling points and piezometers. (See also, Figure 6, which includes these and all sampling sites discussed in this report, and Appendix 2 which describes the location of each site).

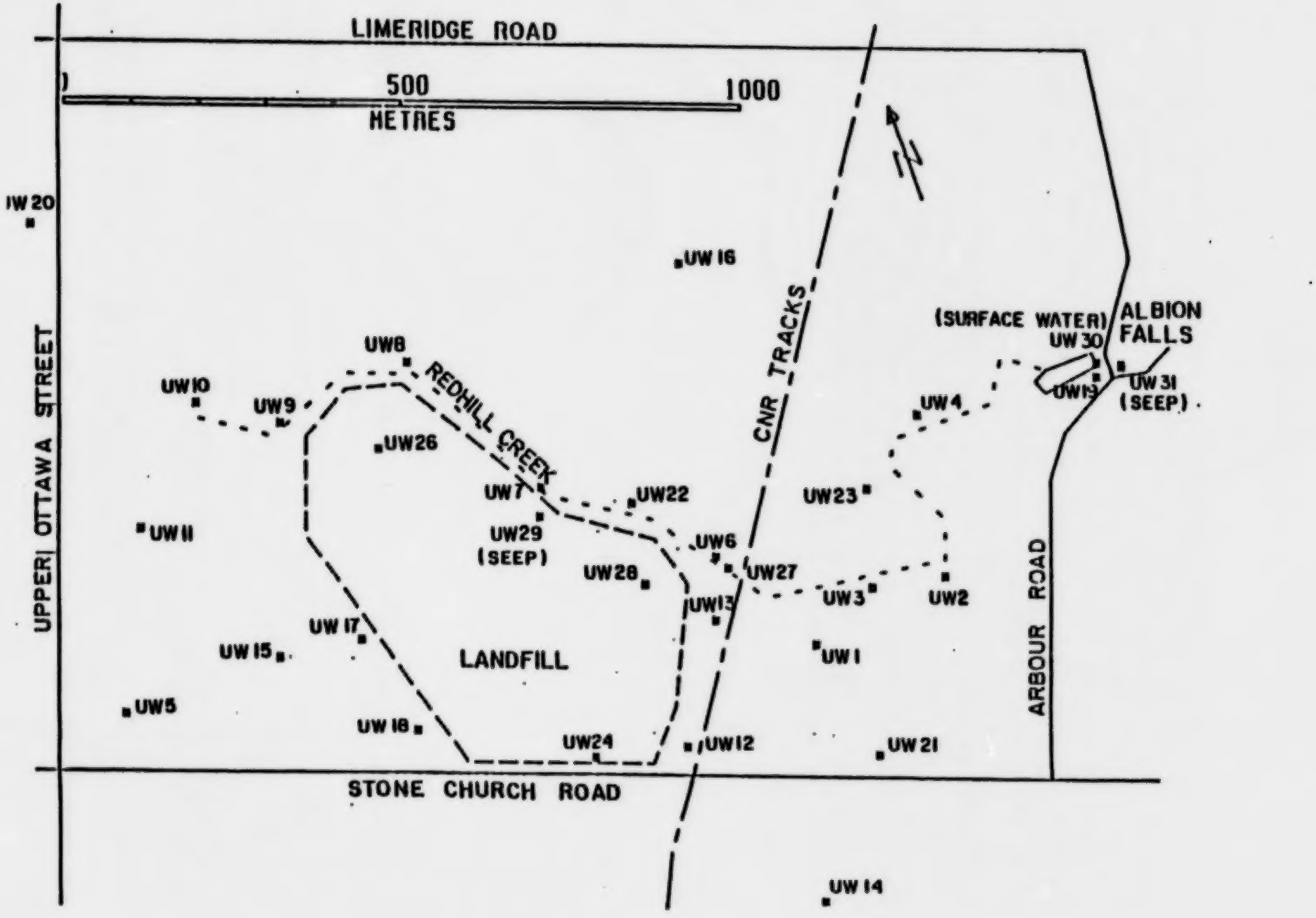

LIMERIDGE ROAD
0
500
1000
METRES
IW20
UW16
CNR TRACKS
(SURFACE WATER)
ALBION FALLS
UW30
UW19
UW31
(SEEP)
UPPER OTTAWA STREET
UW8
REDHILL CREEK
UW10
UW9
UW26
UW4
UW7
UW22
UW23
UW29
(SEEP)
UW11
UW6
UW27
UW28
UW3
UW2
UW13
ARBOUR ROAD
UW17
UW15
LANDFILL
UW1
UW5
UW18
UW24
UW12
UW21
STONE CHURCH ROAD
UW14

FIGURE 8: Regional Geologic Setting of the Landfill

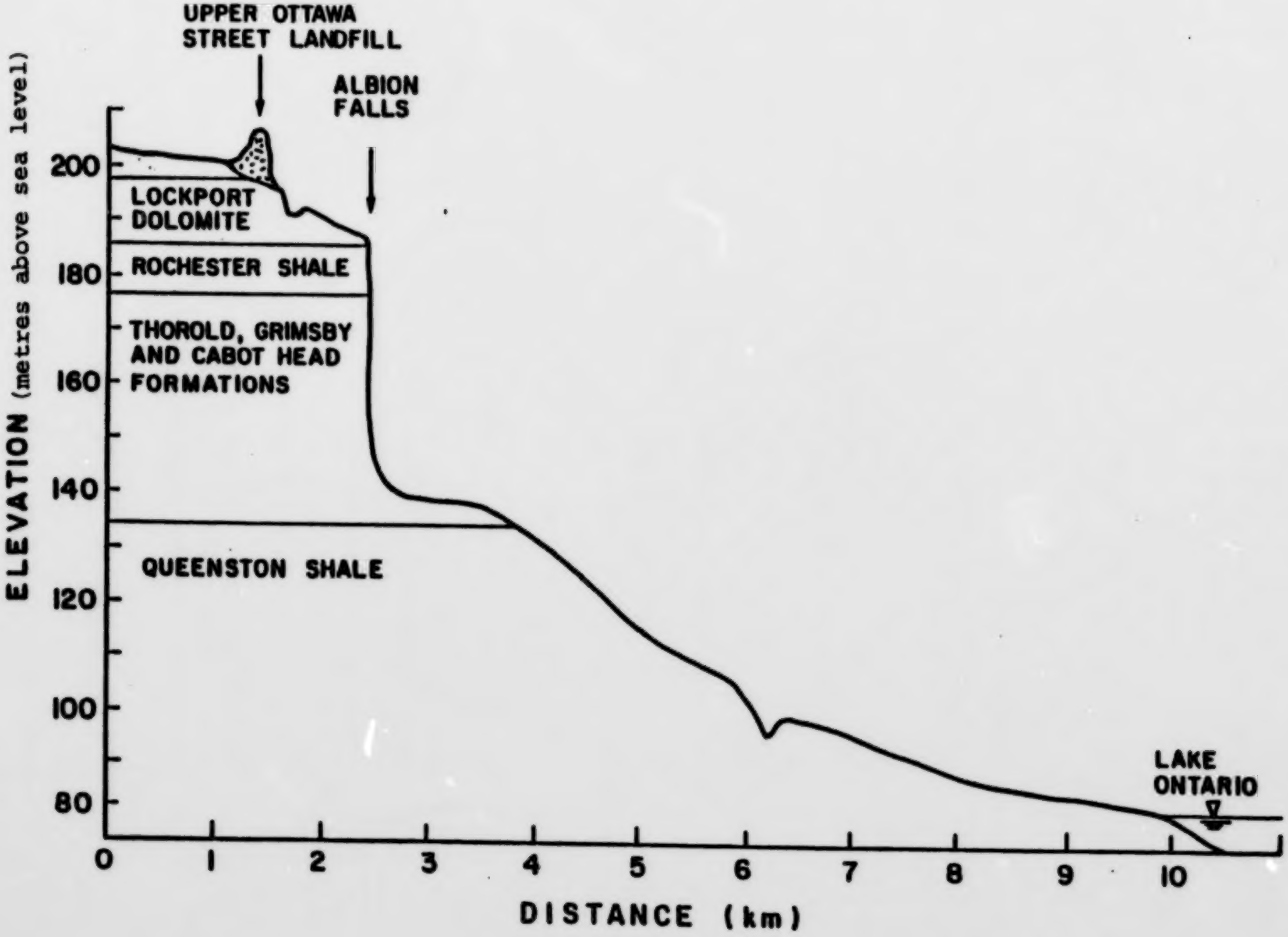
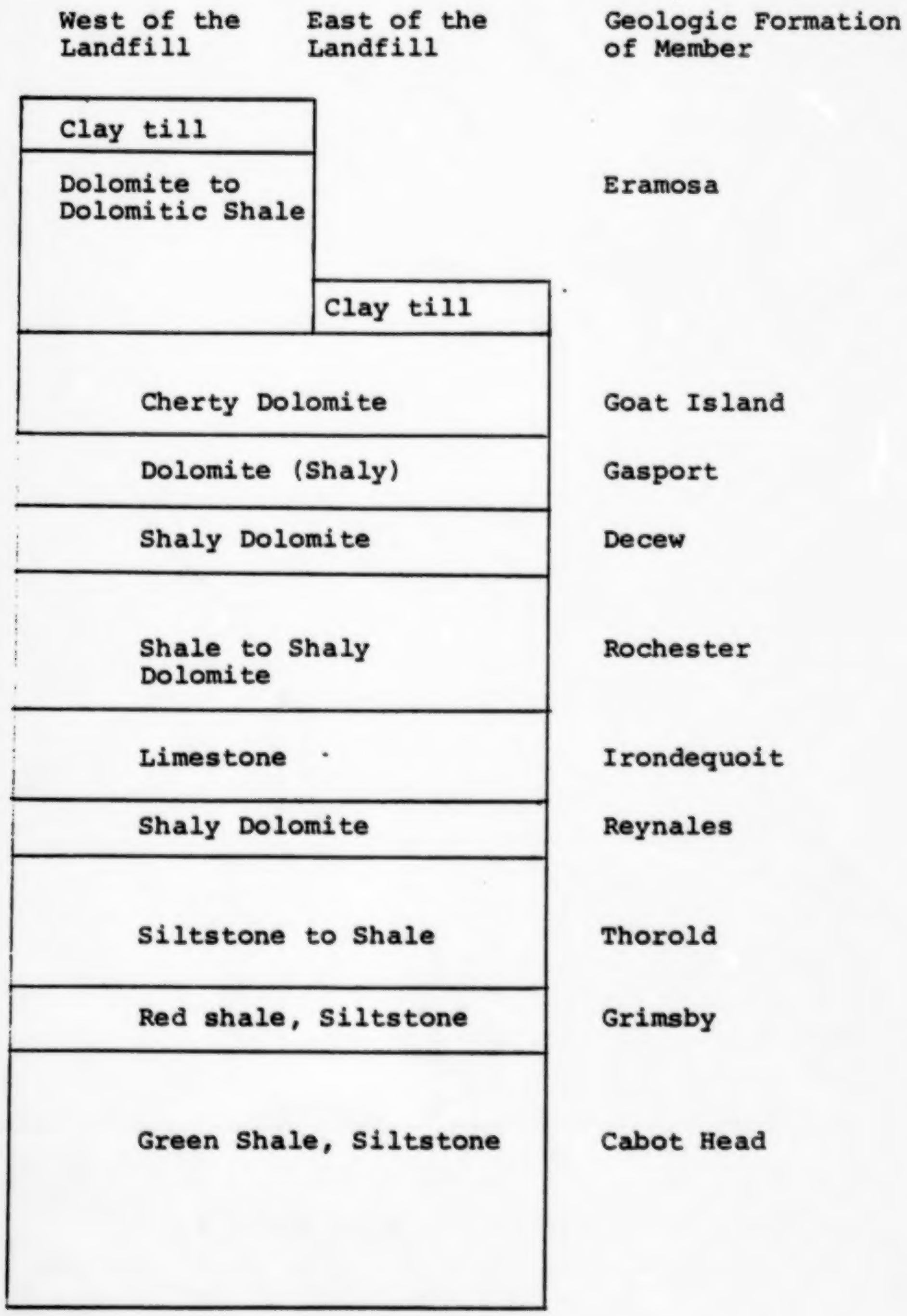

UPPER OTTAWA STREET LANDFILL
ALBION FALLS
LOCKPORT DOLOMITE
ROCHESTER SHALE
THOROLD, GRIMSBY AND CABOT HEAD FORMATIONS
QUEENSTON SHALE
LAKE ONTARIO
ELEVATION (metres above sea level)
200
180
160
140
120
100
80
DISTANCE (km)
0
1
2
3
4
5
6
7
8
9
10

FIGURE 9: Schematic Vertical Geologic Sections (range from 40 to 60 m thick)


West of the Landfill
East of the Landfill
Geologic Formation of Member
Clay till
Dolomite to Dolomitic Shale
Eramosa
Clay till
Cherty Dolomite
Goat Island
Dolomite (Shaly)
Gasport
Shaly Dolomite
Decew
Shale to Shaly Dolomite
Rochester
Limestone
Irondequoit
Shaly Dolomite
Reynales
Siltstone to Shale
Thorold
Red shale, Siltstone
Grimsby
Green Shale, Siltstone
Cabot Head

A thin veneer of clay till (one to three metres thick) covers much of the area except to the east of Redhill Creek where a clay till ridge about 15 metres in thickness is present.

To the west of the landfill there is a 15 to 20 metre thick dolomite shale unit, which is characterized by mostly tight horizontal or lateral fractures. This unit is known as the Eramosa Member.

Immediately underneath the landfill is the Lockport dolomite formation, which is approximately 10 metres thick and consists of three different units of dolomite. The uppermost layer is described as "cherty" dolomite of the Goat Island formation, and it contains large fractured zones. The middle layer is Gasport dolomite, a massive dolomite with very few fractures. The bottom unit is the Decew dolomite; it is very tight with almost no fractures and grades into the underlying shale.

Underlying the Lockport dolomite group is the Rochester shale which is approximately 7 to 10 metres thick and is only slightly fractured, primarily along the thin bedding planes.

Below the Rochester shale is a one metre thick layer of porous limestone called the Irondequoit formation which is underlain by a two to four metre thick Reynales dolomite layer containing horizontal fractures.

Next are the Thorold and Grimsby formations which are approximately five to ten metres thick consisting of siltstone and shale containing numerous fractures.

The last layer of rock above the Queenston shale is the Cabot Head formation of green shale and siltstone, which is approximately 20 to 30 metres deep and has a high degree of fracturing.

The most important characteristic of these rock formations for the groundwater study of the Upper Ottawa Street landfill is the amount of fracturing that occurs in each of the rock units and how well connected the fracture zones are because these are the pathways through which groundwater and leachate will flow.(3)

D. CHARACTERISTICS OF GROUNDWATER FLOW

As stated, one objective of the hydrogeological study commissioned by the Study Committee was to determine the direction and rate of flow of contaminated groundwater from the landfill site.

The pattern of groundwater flow through any medium is influenced by three hydrogeological properties: hydraulic conductivity, hydraulic gradient, and porosity. The following sections present the results and the conclusions reached concerning the direction of groundwater flow. In a subsequent section, hydraulic conductivity and gradient results are combined with estimates of fracture porosities to calculate the velocity of contaminated groundwater flow.

D1. HYDRAULIC CONDUCTIVITY

Hydraulic conductivity is defined as the capacity of a porous medium to transmit a fluid. The movement of water from one point to another in a porous medium takes place when a difference in water pressure exists between these two points. Hydraulic conductivity measures the amount of water that will flow through a given area of porous medium under a given difference in pressure and is usually expressed as centimetres per second. Groundwater moves in horizontal and vertical pathways through fractures in the rock. Low hydraulic conductivity values, in the order of 1×10^{-6} to 1×10^{-9} cm/sec., are observed if the rock is only slightly fractured. High values, in the range of 1×10^{-2} to 1×10^{-3} cm/sec., result if the rock contains numerous, large and well connected fractures.

Hydraulic conductivities were measured by three methods: well response testing at the various depths for almost all the multilevel piezometers installed during the study; borehole packer testing at selected depths in an open borehole; and pumping various zones within an open borehole and monitoring water level responses in wells surrounding the pumping well to determine the effect on water levels in nearby piezometers. More than one test method was used by the Waterloo Research Institute because of the need to obtain data from the large network of multilevel piezometers for both horizontal and vertical hydraulic conductivities, and the difficulty in doing measurements in fractured rock. The results were relatively consistent using the three approaches over a wide range of conductivity values at the same sites.

Although the groundwater flow system is complex and different zones in the system responded in a very irregular manner, several important conclusions can be drawn from the WRI findings(4):

- The shallow cherty dolomite layer of the Lockport unit gave relatively high hydraulic conductivity values for both horizontal and vertical flow, on the order of 1×10^{-2} to 1×10^{-3} cm/sec., which is equivalent to a moderately permeable fine or medium grained sand. There are numerous and extensive open, closely-connected fractures in this rock, which indicate significant horizontal and vertical flows of groundwater.
- For the Rochester shale, lying below the Lockport dolomite, the hydraulic conductivity values for horizontal flow were generally low - between 5×10^{-6} and 1×10^{-9} cm/sec., which is equivalent to a slightly permeable unfractured silt or clay. There are many fractures in the Rochester shale but these are generally very small (e.g., along the horizontal bedding planes and often infilled with clay) indicating a

relatively small amount of flow, especially in the vertical direction. On the other hand, a few hydraulic conductivity values in this layer were much higher than the typical range (e.g., the highest value was 1.5 x 10^{-3} cm/sec.) which suggests the existence of local extensive fracture zones in the Rochester shale that have a much higher hydraulic conductivity than that typically found in this rock.

- Hydraulic conductivity values were also determined at a number of locations in the rock units underlying the Rochester shale. Values in the Irondequoit and Reynales formations ranged from 10^{-5} to 10^{-8} cm/sec. Values in the Thorold and Grimsby formations ranged from 5 x 10^{-6} to 2 x 10^{-9} cm/sec.

These results show the potential for groundwater to flow both horizontally and vertically through the fractured rock. The top layer of the Lockport Dolomite, which extends five to ten metres below ground surface, is highly conductive to horizontal flow. The Rochester shale, lying beneath the Lockport dolomite, is generally not conducive to horizontal groundwater flow, but the rock formations below the Rochester shale are more permeable. Therefore, given the connection of vertical fractures in localized areas of the Rochester shale between the Lockport and deeper rock units, some groundwater will flow through the Rochester shale into the rock beneath it and then flow through further networks of horizontal and vertical fractures.

D2. HYDRAULIC GRADIENTS

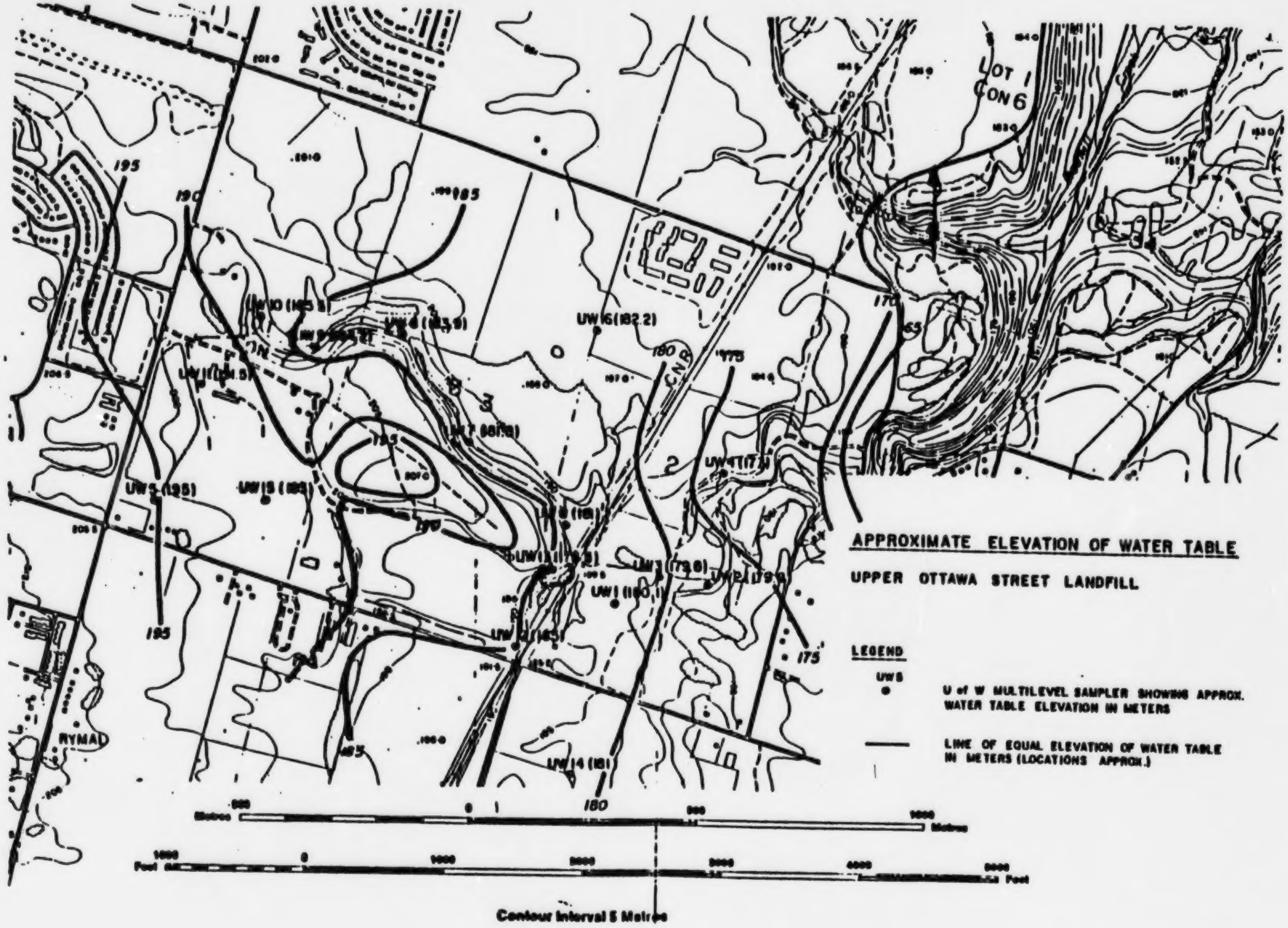
Hydraulic gradients in the horizontal and vertical directions, together with hydraulic conductivity, determine the relative rates of horizontal and vertical flow of groundwater. Horizontal hydraulic gradients are determined by the general slope of the water table, the greater this slope the greater the tendency for lateral flow. Vertical hydraulic gradients are determined by the rate of change of hydraulic pressure with depth below the water table.

D2.1 Horizontal Gradient

Horizontal hydraulic gradients were determined by detailed, routine monitoring of water levels in the multi-level piezometers. Figure 10 shows a generalized water table contour map. This map is a composite of water levels measured by piezometers during the study. Although the water levels change somewhat during the year (i.e., higher during spring recharge by approximately 1.2 metres at site 6 in Figure 6) the general trend remains the same.

The data on the water table map demonstrates that the downward slope of the regional water table is from west to east. The elevation of the water table decreases from 195 metres (above sea level) west of the landfill to 185 to 190 metres at the site. To the east of the landfill, the elevation continues to decrease

FIGURE 10: Water Table Map


APPROXIMATE ELEVATION OF WATER TABLE
UPPER OTTAWA STREET LANDFILL
LEGEND
UW5
U of W MULTILEVEL SAMPLER SHOWING APPROX. WATER TABLE ELEVATION IN METERS
LINE OF EQUAL ELEVATION OF WATER TABLE IN METERS (LOCATIONS APPROX.)
Contour Interval 5 Metres
Metres
Feet
LOT 1
CON 6
CNR
RYMAL
195
190
185
180
175
UW5 (195)
UW15 (189)
UW16 (182.2)
UW1 (180.1)
UW14 (181)
UW4 (177)
UW3 (179.0)
UW2 (179.9)

consistently to a level of 165 to 170 metres at Albion Falls. These data establish that the general direction of horizontal groundwater flow is east away from the landfill towards Albion Falls.

The existence of a water table mound within the landfill is evident from the water table measurements. Mounding is the result of greater infiltration of precipitation into the landfill relative to the rate of flow out of the landfill. While a cover was placed on the landfill in 1980-81 to reduce infiltration, the height of the mounded water has not changed appreciably since the measurements by Gartner Lee Associates in 1979-81, which showed the height of the mound to vary between 186 and 188 metres (above sea level) at site 16 (Figure 6). In 1983-84, the WRI measured the height of the mound to be 187 to 188.5 metres at the same location. This suggests that the rates of infiltration into and flow out of the landfill are now in balance, or that insufficient time has elapsed between the two sets of measurements to make a significant impact on the very large mound contained in the landfill site. It is not possible to predict how long it will take the mounded water table to decline or if any dissipation will occur, given the present condition of the landfill cover.

The elevation of the mounded water table within the landfill is higher than the water table elsewhere in the area, thus, leachate from the landfill is seeping into the bedrock under and around the landfill periphery. While leachate can move away from the landfill into the groundwater in all directions, the consultants have concluded that it cannot migrate horizontally farther than 100 metres other than in an easterly direction toward the escarpment because of the regional slope of the water table towards Lake Ontario.

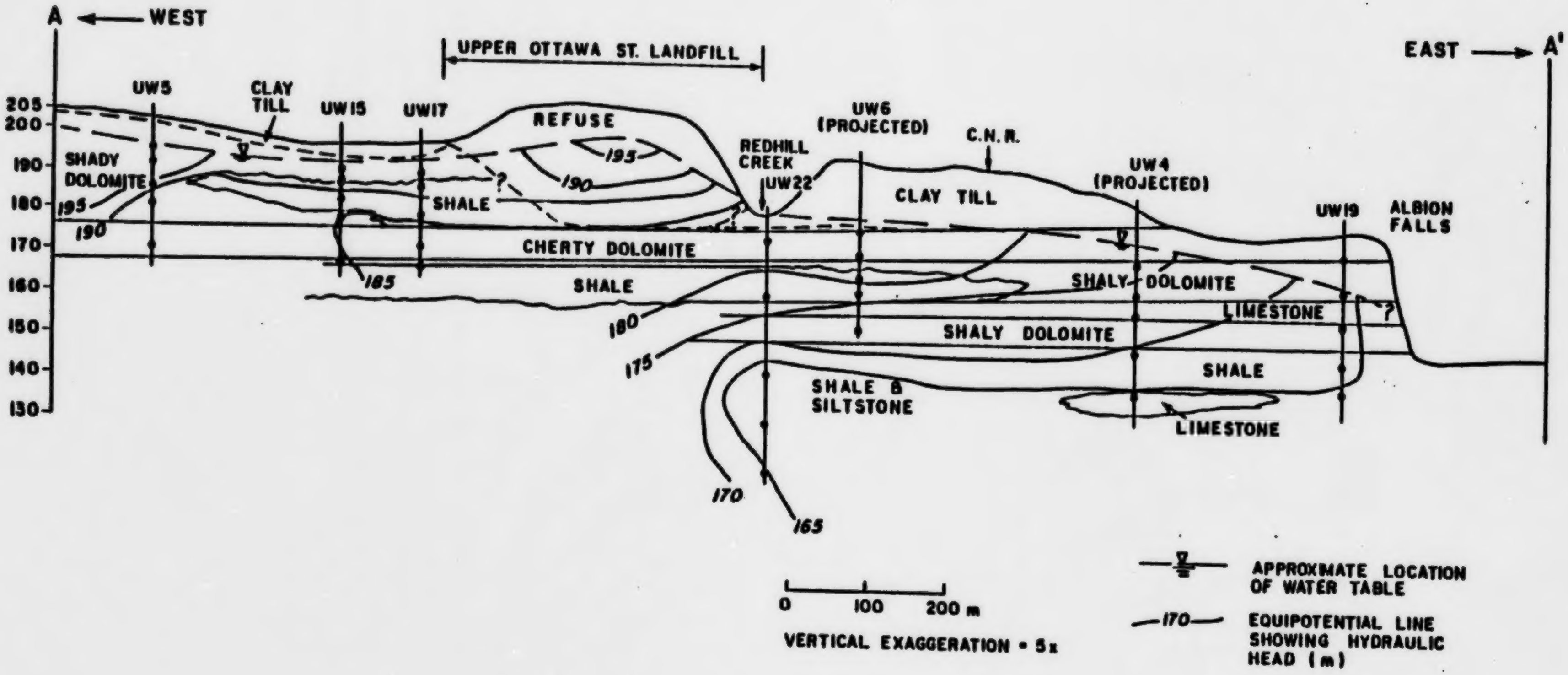
D2.2 Vertical Gradient

Vertical gradient profiles showing lines of equal hydraulic pressure or head (equipotential lines) are shown in Figure 11 for a vertical cross-section in an east to west direction. The data show a general decrease in hydraulic pressure or head with depth, indicating a potential for vertical groundwater flow between the landfill and Albion Falls.

Other conclusions which can be drawn from the vertical gradient measurements are as follows:

- On the western periphery of the landfill there is a strong vertical gradient that decreases further west. Its existence indicates that any groundwater flow west of the landfill will be primarily vertical.
- The Lockport dolomite underlying the landfill has a very small vertical gradient near the landfill which increases as the distance to Albion Falls decreases.

FIGURE 11: Vertical Cross Section Showing Hydraulic Head


A ← WEST
EAST → A'
UPPER OTTAWA ST. LANDFILL
205
200
190
180
170
160
150
140
130
UW5
CLAY TILL
UW15
UW17
REFUSE
195
190
?
REDHILL CREEK
UW22
UW6 (PROJECTED)
C.N.R.
CLAY TILL
UW4 (PROJECTED)
UW19
ALBION FALLS
SHADY DOLOMITE
195
190
SHALE
CHERTY DOLOMITE
185
SHALE
180
175
SHALY DOLOMITE
LIMESTONE
?
SHALY DOLOMITE
SHALE
SHALE & SILTSTONE
LIMESTONE
170
165
0
100
200 m
VERTICAL EXAGGERATION = 5x
APPROXIMATE LOCATION OF WATER TABLE
170
EQUIPOTENTIAL LINE SHOWING HYDRAULIC HEAD (m)

- In the Rochester shale there is generally a relatively strong downward vertical gradient, with the exception of localized pockets of natural gas encountered in the vicinity of Site 23 (Figure 6), which exert an upward pressure.
- Below the Rochester shale, the vertical gradients of the various rock formations are highly variable depending on the amount and degree of fracturing.
- There is a vertical gradient below the base of Albion Falls. There could also be a small upward gradient. If such a gradient exists, it could result in a very small discharge of groundwater at the base of Albion Falls at ground level or possibly directly into the Redhill Creek.

Overall, it can be concluded that the groundwater is moving eastward from the landfill with a vertical flow pattern that increases toward the escarpment face. The important question as to whether some portion of the flow is through the face of the escarpment or whether essentially all of it passes under the base of Albion Falls and ultimately to Lake Ontario is discussed in section F of this chapter.

E. LEACHATE PRODUCTION

The rate at which leachate leaves the landfill has been estimated by two methods. The first, the water budget method, was used by Gartner Lee Associates, and assumes the amount of leachate leaving the landfill by seepage into the bedrock is equal to the water entering the landfill by infiltration. This would appear to be a reasonable assumption, despite the placement of a cover on the site five years ago, since the level of mounding has not changed appreciably between the times the Gartner Lee Associates and the Waterloo Research Institute measurements were made.

Gartner Lee based their calculations on an average annual rate of precipitation of 79 cm and an estimated rate of evapotranspiration of 43 cm on the non-vegetated cover. They assumed that the difference between the two, amounting to 35 cm, infiltrates into the landfill over the entire landfill surface. From this, they calculated that the average rate of infiltration into the landfill is 2.65 litres per second. This is equivalent to 83.6 million litres or 22 million gallons per year. In this calculation no account has been taken of run-off, which will be appreciable, especially on the north and east sides of the site.

The second method (used by the WRI) estimates the rate of horizontal flow for the shallow permeable zone in the cherty dolomite and shaly dolomite at the periphery of the landfill. It is assumed that the leachate that enters this lateral flow zone under the landfill represents essentially all of the leachate that emanates from the landfill.

The rate of lateral flow is determined by the hydraulic conductivity and hydraulic gradient in the shallow bedrock zone. Since the measured values of the former vary by a factor of ten, the calculated rate of lateral flow has a corresponding broad range of values, amounting to 2.1 to 21 litres per second.* The low end of this range corresponds to the 2.65 litres per second estimated by Gartner Lee Associates.

It is important to recognize that the two estimates are not directly comparable. The method used by the WRI measures the total lateral flow under the landfill. Only a part of this is leachate from the landfill as estimated by the water-balance method. In addition, there is an unknown contribution from groundwater originating upgradient from the site. Since the low end of the range calculated for total lateral flow agrees with the estimated volume of leachate due to infiltration, it seems reasonable to assume that the rate of leachate production is at least 2.65 litres per second or 83.6 million litres per year. It may well be several times as much.

It is of interest to note that the WRI has estimated that the total amount of leachate in the landfill, based on the dimensions of the water mound at the time of measurement, is 1,300 million litres. This is some fifteen times greater than the lower estimate of 83.6 million litres for the annual rate of leachate production.

To place this volume of storage leachate into perspective, the WRI estimates the total volume of void space (i.e., rock fractures) in the probable zone of contamination stretching to Lake Ontario. They assume this zone to be 1,000 metres wide, 30 metres deep and 9 kilometers long, and that fractures in the rock, on average, amount to one-thousandth (0.1%) of total rock volume in this zone. The calculated value of void space is 270 million litres, which is one-fifth the estimated volume of leachate in the landfill (1,300 million litres). The consultants conclude that "it is reasonable to expect on the basis of any reasonable selections of rock parameter values that the 1,300 million litres estimated to exist in the landfill would be sufficient to produce a plume that would extend to Lake Ontario." Also, based on the estimated lower limit of 2.65 litres per second, or 83.6 million litres per year, of leachate flow from the landfill, it would require only a few years of leachate production to develop this extensive plume of 270 million litres.

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* In addition to leachate moving into the bedrock at the bottom of the landfill, some is flowing into the leachate collection system and some is seeping through the cover at the base of the steep slope on the north side of the site. Both, however, are very small relative to the amount estimated to flowing into bedrock. Furthermore, no direct leachate seepages were found by WRI researchers in the bed of the Red Hill Creek.

As stated earlier, there has been no apparent reduction in the landfill water table mound since the Gartner Lee measurements in 1979. This indicates that there has been no appreciable reduction in the infiltration of rain and snowmelt into the landfill since the cover was installed in 1980-81, or that the difference between the rate of infiltration and out-flow is very small relative to the total volume of leachate stored within the site. The WRI calculations are consistent with the latter.

If the cover were to be constructed in such a fashion as to make it essentially impermeable, the water table would eventually decline to a level near the bottom of the landfill. It is important to recognize, however, that lateral eastward groundwater flow through the landfill, even under these conditions, would continue to cause leachate to be carried from the landfill into the shallow permeable dolomite zone. The rate of flow would, of course, be smaller and water would not be percolating through the full depth of the landfill.

F. VELOCITY OF GROUNDWATER FLOW

Significant as it is to know that the flux of leachate (volume per unit time) is sufficient to produce a plume stretching to the escarpment and beyond to Lake Ontario, it is important, as well, to have a measure of the actual rate of flow in both horizontal and vertical directions (distance per unit time).

Velocity of groundwater flow is a function of hydraulic conductivity, hydraulic gradient and porosity. For fractured rock, porosity represents the percentage of unit volume of rock occupied by open fractures through which groundwater flows. The WRI used several methods to estimate porosity for the various rock types. For the shallow bedrock zone (i.e., cherty dolomite and upper shaly dolomite) the fracture porosity was estimated to range between 0.12 and 0.2 per cent and for the underlying shale from 0.015 to 0.13 per cent. The limestone and dolomite of the underlying Irondequoit and Reynales formations and the siltstone and shale of the Thorold and Grimsby formations gave values ranging from 0.2 to 1.3 per cent.

Using these values and the previously measured values for hydraulic conductivity and hydraulic gradient, velocity of flow was calculated for each of the various rock types.

It was found that in the cherty dolomite near the landfill site, lateral (horizontal) velocities range from 1.5 to 20 metres per day, which is extremely high compared to vertical velocities estimated at about 1 centimetre per day. To the east of the landfill, the vertical flow velocity increases until, near Albion Falls and the face of the escarpment, it reaches the same range as the horizontal velocity.

From these results, it would appear that in the vicinity of the escarpment a significant fraction, perhaps most of the water within the cherty dolomite, either migrates along the base of the cherty dolomite or migrates with depth through the Rochester shale.

Because of the wide range of values estimated for the hydraulic conductivity and porosity of the Rochester shale, the calculated values for vertical velocity in this rock formation have an enormous spread, from 0.2 centimetres per year to 0.2 metres per day. If the average vertical velocities were near the lower end of this range, the Rochester shale would be essentially impermeable, and one would expect to see extensive seepages at the face of the escarpment at the boundary between the dolomite and Rochester shale zones. On the other hand, if the overall vertical velocity were near the upper end of this calculated range, the groundwater leaving the dolomite sections should pass through the Rochester shale into the Thorold, Grimsby and Cabot Head limestone formations and then migrate below the base of the escarpment (see Figure 9).

Although two or three small seeps have been observed at the face of the escarpment in the Albion Falls area, the actual amount of water is small compared to that which might be expected if the Rochester shale constituted a barrier to vertical flow. In the opinion of the WRI, there is evidence, both chemical and hydrogeological, that the pond located adjacent to Albion Falls is the likely source of water for these seeps.

In order to test the hypothesis that most of the groundwater moving eastward from the landfill site has passed through the Rochester shale before reaching the escarpment, the Waterloo Research Institute calculated the vertical hydraulic conductivity needed in the shale to allow the water in the upper dolomite to migrate through it. This was found to be 1.3×10^{-6} centimetres per second. While this is on the high end of the average values found for this rock formation, a value of vertical hydraulic conductivity of 5×10^{-6} centimetres per second was observed at UW 3-4 (in Figure 7, which is site 23 in Figure 6) in this shale. Since a greater degree of fracturing in this zone can be expected near the escarpment, the WRI concludes "that the potential definitely exists for the water emanating as leachate from the landfill into the cherty dolomite to move completely through the Rochester shale by the time it migrates to the Albion Falls area."

In summary, based on estimates of the rate of lateral flow of groundwater through the cherty dolomite of 1.5 to 20 metres per day, contaminated groundwater should have reached the vicinity of Albion Falls within a very few years. Before doing so, however, it will have migrated through the Rochester shale and underlying limestone formations and passed under the base of the escarpment.

Although no hydrogeological data were acquired for areas below the escarpment, the WRI is of the opinion that much or all of the leachate impacted groundwater does not surface until it passes below the shoreline of Lake Ontario. Since the quantity of landfill contaminated water relative to total groundwater flowing beyond Albion Falls is very small, contaminants will be greatly diluted before discharge.

References

1. Gartner Lee Associates Limited, Hydrogeological Study of Leachate and Gas Impacts (Stage 2) at the Upper Ottawa Street Landfill, Hamilton-Wentworth, September 1980.

2. John A. Cherry and Paul E. Johnson, "A Multilevel Device for Monitoring in Fractured Rock," Groundwater Monitoring Review, Summer 1982, 41-4.

3. J.A. Cherry, and J.F. Barker, Hydrogeological Investigations of the Upper Ottawa Street Landfill Site: A Progress Report for the Period April 1982 to February 1983, Institute of Groundwater Research at the University of Waterloo, March 17, 1983.

4. J.A. Cherry, J.F. Barker, R.J. Blackport, and J.E. Barbash, Hydrogeological Investigations of the Upper Ottawa Street Landfill Site in Hamilton, Ontario. (Final Report), Institute of Groundwater Research at the University of Waterloo, October 1984.

CHAPTER 7

THE CHEMICAL CONTENT OF GROUNDWATER

TABLE OF CONTENTS

	Page
A. INTRODUCTION	120
B. ANALYTICAL METHODS	121
B1. WATER QUALITY PARAMETERS AND HEAVY METALS	121
B2. ORGANIC POLLUTANTS	121
B2.1 Gas Chromatography (GC)	121
B2.2 Semi-Quantitative Gas Chromatography-Mass Spectrometry (GC-MS)	121
B2.3 Electron Capture-Gas Chromatographic Analysis for PCBs and Pesticides	122
B2.4 Tritium Analyses	122
C. FINDINGS	122
C1. WATER QUALITY PARAMETERS	122
C2. HEAVY METALS	122
C3. ORGANIC POLLUTANTS IN GROUNDWATERS	124
C4. POLYCHLORINATED BIPHENYLS (PCBs) AND CHLORO-ORGANIC PESTICIDES	126
C5. CHEMICAL CONTENT OF BACKGROUND WATERS	128
D. RECOGNITION OF LEACHATE CONTAMINATION IN GROUNDWATERS	130
E. SEVERITY OF LANDFILL — LEACHATE CONTAMINATION	132
F. CONCLUSIONS	134

Tables **Page**

16 Metals Analyses of Groundwaters 123

17 Results of GC-MS Analysis of Organics in Groundwaters 125

18 EC-GC Analysis of Groundwaters for Chloro-Organic Pesticides 127

19 Chemical Content of Background Groundwaters 129

20 Comparison of Chemical Content of Background Groundwaters, Downgradient Groundwaters and Leachate 131

21 Calculated Maximum Flux of Selected Contaminants Entering Groundwater at the Landfill Site 133

References 135

APPENDIX 4:
Table

1 Water Quality and Inorganic Analyses of Groundwaters Near to the Landfill

2 Water Quality and Inorganic Analyses of Groundwater Distant from the Landfill

3 GC-MS Analyses of Groundwaters Near to the Landfill

4 GC-MS Analyses of Groundwaters Distant from the Landfill

A. INTRODUCTION

The dimensions of a potential groundwater problem at the Upper Ottawa Street landfill site were set out in the previous chapter describing a hydrogeological study of the landfill carried out by the Waterloo Research Institute (WRI). It was concluded that some of the landfill leachate migrates into the groundwater; the resulting contaminated plume flows primarily east; this plume, before reaching Albion Falls, migrates through the Rochester shale and underlying limestone formations to pass under the base of the escarpment; and the plume could then continue underground or in the Red Hill Creek towards Lake Ontario, while becoming greatly diluted by other ground and/or surface waters.

The purpose of the groundwater chemical analysis program carried out by the WRI group was twofold: 1. to map the shape and size of the contaminated plume, and 2. to determine the extent of groundwater contamination caused by the landfill and the degree to which this contamination becomes attenuated through dilution or absorption as the plume moves away from the site.

In studies of landfills located on sand or gravel, certain chemicals have proved to be reliable "tracers" for the identification of leachate contamination.(1) Based on these earlier studies it was anticipated that at the Upper Ottawa Street landfill, several of the general water quality parameters and at least one organic compound would prove to be unique identifiers of leachate. Unfortunately, the situation proved to be very much more complicated. Not only did natural background waters frequently contain higher concentrations of inorganic species than even concentrated leachate, but organic compounds, especially the volatile aromatic hydrocarbons, were also present in appreciable quantities. The latter had their origin in the bituminous, hydrocarbon-rich, organic matter ubiquitous to the bedrock.

Since the impact of leachate contamination of groundwaters can only be assessed in relation to natural or background water quality, considerable attention was given to the chemical content of the latter. In addition to the chemical analyses of a large number of groundwater samples taken at various depths in boreholes comprising a network located both up and downgradient of the landfill, measurements were made of groundwater tritium (^3H) content.* Tritium provided an estimate of groundwater age (the length of time the different groundwaters had been in contact with bedrock since their precipitation as rain or snow).

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* Tritium is a radioactive isotope of hydrogen. While it occurs naturally in groundwaters, its concentration was greatly increased as a result of atmospheric nuclear testing in the early 1950s.

B. ANALYTICAL METHODS

B1. WATER QUALITY PARAMETERS AND HEAVY METALS

General water quality parameters and inorganics, including heavy metals, were analyzed from May through December of 1983. Analyses were performed by WRI and the Ministry of the Environment using standard procedures.(2) A detailed sampling protocol was developed for ensuring the integrity of sampling procedures, and sufficient quality assurance checks were performed to ensure reliability of the analytical data.

B2. ORGANIC POLLUTANTS

Because the groundwater study required the analysis of a large number of samples taken from five sampling depths in a network of 26 boreholes, it was not feasible to employ quantitative GC-MS as a routine analytical method. Instead, simple gas chromatography was used for the routine analysis of some selected volatile organics. In addition, semi-quantitative GC-MS analyses were carried out on representative groundwater samples (those samples in which significant peaks were found by GC screening).

B2.1 Gas Chromatography (GC)

Methods similar to the United States EPA Method 602 were used by the WRI for the gas chromatographic analysis of the volatile organics. The compounds targeted for quantification were benzene, toluene, xylenes, cumene, 1,2,4-trimethylbenzene, chlorobenzene and naphthalene. Pure samples of each compound were used as external standards for purposes of identification, and an internal standard of para-fluorotoluene was used for quantification.

As an independent confirmation of the identity and concentrations of compounds analyzed by the GC method, 11 leachate and groundwater samples were also analyzed by the Mann Testing Laboratories using quantitative GC-MS. In most cases, the agreement between the two methods was quite good. Exceptions are encountered for benzene and toluene in concentrations in excess of 5-10 ppb. In these instances, the GC method gave higher values due to the presence of high concentrations of interfering species.

B2.2 Semi-Quantitative: Gas Chromatography-Mass Spectrometry (GC-MS)

Three laboratories were involved in the GC-MS analysis of groundwater samples: Ontario Ministry of the Environment, Stanford University and the Mann Testing Laboratories (MTL). In the case of analyses performed by MTL, the WRI prepared extracts of base-neutral and acidic compounds, MTL performed the GC-MS and the WRI analyzed the data. Each semi-quantitative analysis was accompanied by a computer scan of the observed spectra and matching with the EPA/NIH "library" for qualitative identification. The method is briefly described in Chapter 4, page 55. While this method gives values for the concentration of individual compounds that are only approximate (within a factor of ten), the relative concentrations obtained from sample to sample are fairly accurate (within a factor of 2).

B2.3 Electron Capture-Gas Chromatographic Analysis for PCBs and Pesticides

The Ontario Ministry of the Environment and Beak Laboratories carried out EC-GC analyses of groundwater samples for polychlorinated biphenyls (PCBs) and chloro-organic pesticides for Gartner Lee Associates in 1980-81.(3,4) The EC-GC method is briefly described in Chapter 5, page 76.

B2.4 Tritium Analyses

The concentration of tritium in groundwater samples was determined mass spectrometrically.(5)

C. FINDINGS

C1. WATER QUALITY PARAMETERS

Most of the parameters were found to vary over a wide range of values, with no obvious relationship to the location of the sampling site in relation to the landfill. As will be seen in Section C5 of this chapter, the primary cause of this variation is groundwater age (the length of time the groundwater has been in contact with bedrock) rather than contamination by leachate. Summaries of water quality data for sites near and distant from the landfill are shown in Tables 1 and 2 of Appendix 4.

C2. HEAVY METALS

Table 16 presents the results of the heavy metal analysis of groundwaters from boreholes located both near and distant from the landfill site. It can be seen that higher levels were found for iron, manganese and chromium near to the site, while the reverse was observed for cadmium and nickel. Frequently, concentrations of the metals were actually found to be higher in the groundwaters than in concentrated leachate (Table 5, Chapter 5). The metal analyses, therefore, are of no assistance in the identification of leachate contaminated groundwaters.

Table 16: **Metal Analyses Of Groundwaters**
parts per million

		Near the Landfill					Distant from Landfill					
	Site 15	Site 10[a]	Site 13	Site 21	Site 30[a]	Site 33	Site 4[a]	Site 14[a]	Site 23[a]	Site 25[a]	Site 28	Drinking Water Criteria[b]
Sampling Depth:	(Leachate)	6.4m	48.5m	12.2m	21m	15.6m	10m	31.7	12.6m	7.2m	5.9m	
arsenic	0.003	0.001	0.001	0.001	0.003	0.001	0.001	0.001	0.001	0.001	0.02	0.05
cadmium	0.005	0.01	0.005	0.005	0.004	0.005	0.01	0.03	0.009	0.009	0.005	0.005
chromium	0.04	0.04	0.03	0.40	0.24	0.13	0.04	0.11	0.05	0.04	0.03	0.05
copper	0.02	0.07	0.38	0.41	0.36	0.39	0.05	0.88	0.37	0.03	0.06	1.0
iron (total)	3.20	0.098	0.64	7.3	0.48	0.14	0.33	0.89	0.35	2.37	0.05	0.3
lead	0.03	0.06	0.05	0.08	0.04	0.06	0.05	0.60	0.05	0.04	0.03	0.05
manganese	NR	0.03	0.33	1.7	0.99	0.75	0.05	1.35	0.51	0.52	0.08	0.005
nickel	0.15	0.07	0.006	0.01	0.009	0.006	0.02	0.08	0.02	0.02	0.02	
zinc	0.03	0.022	0.009	0.41	0.60	0.05	0.01	0.09	0.04	0.13	0.03	5.0

Notes: Location of sampling sites shown in Figure 6.

All samples collected between May and December of 1983 and analyzed for the Waterloo Research Institute by the Ontario Ministry of the Environment.

[a] Values reported are average of two samples,
[b] Ontario Ministry of the Environment Drinking Water Objectives (where available).

NR means the presence or absence of the compound was not reported by the laboratory.

With the exception of arsenic, copper and zinc, the concentrations of metals exceed drinking water standards. Nevertheless, the extent of heavy metal contamination is relatively low and, therefore, should not be of concern, especially since groundwaters in the area are not used for drinking water.

C3. ORGANIC POLLUTANTS IN GROUNDWATERS

Table 17 presents the results of the semi-quantitative GC-MS analyses of groundwaters from representative boreholes located close to and some distance from the landfill. (See Figure 6 for the location of the boreholes). The compounds selected for presentation in this table parallel those presented in Table 7 for the organics in leachate, except that two PAHs, naphthalene and methylnapthalene, are also included. More detailed analytical data for groundwaters are shown in Tables 3 and 4 of Appendix 4.

The aromatic hydrocarbons, benzene, toluene, xylenes, and the C_3- and C_4-benzenes, were commonly found, particularly in groundwaters near to the landfill. Polycyclic aromatic hydrocarbons were generally absent from the groundwaters, except for small concentrations of naphthalene and the methylnaphthalenes.

The chlorinated hydrocarbons, dichloromethane and dichlorobenzene, were present in a number of groundwater samples, the former much more frequently in groundwaters near to the landfill. The general absence or, where present, the low concentrations of halogenated hydrocarbons, is typical of the results obtained for leachate samples generally, as well as for surface waters. (Tables 7 and 11, Chapter 5).

The phthalates, di-butylphthalate and bis(2-ethylhexyl) phthalate, were frequently encountered, usually in higher concentrations at sites near to the landfill. Since the WRI researchers demonstrated the presences of phthalates in piezometer and sampling materials, it is difficult to know the extent to which the presence of these substances in groundwaters, especially from distant sites, can be attributed to the landfill.

The phenolic compounds, phenol, cresols and xylenols, although encountered at a number of sites, were present in much lower concentrations than in most leachates.

Tetrahydrofuran (THF) was found in a number of groundwater samples, reaching concentrations as high as those found in leachates in two boreholes located close to the landfill. THF is an ingredient in the glue used to install some of the piezometers. Since this compound, however, was present in groundwaters from piezometers where glue was not used, the WRI researchers are of the opinion that most of the THF found in the groundwaters originates from some other source.

Table 17: Results Of The GC-MS Analyses Of Organics In Groundwaters
parts per billion

	Near to the Landfill							Distant from the Landfill								
	Site 15^a	Site 10^a	Site 13^b	Site 20^a	Site 21^b	Site 30^c	Site 33^b	Site 4^a	Site 25		Site 23^a		Site 28^a		RQL^d	Drinking Water Criteria^{e,f}
Sampling Depth	(Leachate)	4.6m	48.5m	3.7m	12.2m	21m	15.6m	10m	7.2m^b	16.2m^c	4.4m	12.6m	59.m	24.1m		
benzene	6.9	3.5	4.9	0.9	9.0	1.3	ND	BRQL	ND	ND	BRQL			BRQL	1.0	1.0^f
toluene	229	2.0	43.4	0.9	8.2	2.2	85.0	BRQL	1.4	4.8	BRQL			BRQL	1.0	50.0^f
xylenes	332	9.0	3.4	BRQL	2.0	4.1	2.8	BRQL	1.4	0.7	BRQL			1.3	1.0	50.0^f
ethylbenzene	69.4	3.1	BRQL	BRQL	BRQL	BRQL	BRQL	BRQL	ND	0.2	BRQL			BRQL		50.0^f
C_3-benzenes	275	3.8	ND	BRQL	ND	ND	ND	BRQL	54.0	ND	BRQL			1.2	1.0	50.0^f
C_4-benzenes	212	ND	ND	ND	ND	ND	ND	ND	14.0	ND	ND			ND	1.0	
naphthalene	D	0.5	D	0.8	D	D	ND	BRQL	ND		BRQL	ND	D	0.5	0.4	10.0^f
methylnaphthalenes	ND	0.5	ND	0.5	ND	ND	ND	BRQL	ND		BRQL			0.6		
dichloromethane	ND	6.1	BRQL	ND	ND	5.6	39.6	ND	ND	ND	ND			D	5.0	50.0^f
dichlorobenzenes	ND	BRQL	ND	BRQL	ND	ND	ND	BRQL	9.0	ND	BRQL			BRQL	1.0	20.0^f
di-n-or di-isobutyl phthalate	73	2.9	40.0	17.3	6.0	D	D	4.8	5.0	(D)^g		8.7	2.7		0.4	
bis(2-ethylhexyl) phthalate	350	ND	100	ND	ND	ND	ND	ND	20.0	(D)^g		ND	ND		0.9	4.0^f
phenol	92	10.4	ND	1.5	ND	ND	ND	ND	3.0			BRQL	14.5		1.5	2.0^e
cresols	134	ND	ND	ND	ND	ND	ND	ND	ND			BRQL	ND		3.0	2.0^e
xylenols	576	16.2	ND	ND	ND	ND	ND	ND	7.0			ND	ND		2.0	2.0^e
aniline	ND	ND	ND	BRQL	ND	ND	ND	ND	D			5.6	ND			1.0^f
tetrahydrofuran	23.9	D	166	ND	2.1	D	271	ND	6.0	ND	ND	ND	ND	(D)^g	1.0	50.0^f
1,4-dioxane	26.6	ND	BRQL	ND	ND	ND	ND	ND	4.0	ND	ND			ND	80.0	
benzothiazole	D	4.9	10.0	94.3	238	D	11.0	4.9	D	(D)^g		BRQL	1.4		0.8	

Notes: Location of sampling sites shown in Figure 6.

[a] Analyzed by Stanford University.
[b] Analyzed by the Ontario Ministry of the Environment.
[c] Analyzed by Mann Testing Laboratories.
[d] RQL means Reliable Quantification Limit of the analytical method.
[e] Ontario Ministry of the Environment Drinking Water Objectives (where available).
[f] New York State Proposed Drinking Water Toxics Standards, January 1985 (where available).
[g] Found at another depth in the same borehole.

D means the compound was detected but the amount not determined.
BRQL means Detected but Below Reliable Quantification Limit.
ND means the compound was searched for; if present, the amount is below the detection limit.
Where data are not given in this table, the presence or absence of the compound was not reported by the laboratory.

Next to the phthalates, the most frequently encountered groundwater organic contaminant was benzothiazole, the concentration of which in some groundwaters approaches the highest found in any leachate. This compound also was found to leach from piezometer materials. Nevertheless, the fact that it was not detected at every piezometer sampling point and also the much higher concentrations observed in near as distinct from distant sites, strongly suggest the landfill as the main source of this contaminant.

The overall GC-MS results for groundwaters at certain specific sites merit comment. As shown in Table 17, the sample from the upgradient Site 4, located to the west of the landfill, would appear to be less contaminated than groundwaters from distant downgradient sites. In contrast, Site 25, located at the 7.2m. depth near Albion Falls, stands out as an especially contaminated distant site. With respect to the source of this contamination, the WRI researchers, on the basis of hydrogeological evidence, concluded that the water in this shallow well is a perched water table caused by water seeping into the area from the pond. If this is so, the landfill may not necessarily be the only cause of groundwater contamination at this distant borehole site.

In summary, the extent of groundwater contamination is clearly greater at sites close to the landfill than at the more distant sites. Also, there is some evidence that downgradient distant sites have more contaminants at higher concentrations than upgradient distant sites. Both of these findings are to be expected from the results of the hydrogeological study (see Chapter 6). Nevertheless, because most of the organic contaminants are also found in the natural groundwaters in the general location of the landfill and because the concentrations of the contaminants in the groundwaters generally are only at the parts per billion level, it is not feasible to use the GC-MS results to map a contaminated groundwater plume.

C4. POLYCHLORINATED BIPHENYLS (PCBS) AND CHLORO-ORGANIC PESTICIDES

The Ontario Ministry of the Environment analyzed six groundwater samples from the landfill area for PCBs in 1980. None was detected.

In 1981, the Ministry of the Environment conducted a second EC-GC analysis of seven groundwater samples from the same general area and detected PCBs in groundwaters sampled from two boreholes installed by Gartner-Lee Associates: a concentration of 0.56 ppb of PCBs was found in a borehole near Site 35 and 0.26 ppb at Site 29.

Also in 1981, the Ministry of the Environment and Beak Laboratories carried out an EC-GC analysis for chloro-organic pesticides on duplicate samples of groundwaters collected from Sites 24 and 29. It can be seen from Table 18 that

Table 18: Electron Capture-Gas Chromatographic Analyses of Groundwaters for Chloro-Organic Pesticides[a]
parts per billion

	Site 24	Site 29	RQL[b]
Sampling Depth	9.8m	15.5m	
HCB	ND	ND	0.01
alpha BHC	0.008	0.020	0.001
beta BHC	ND	0.002	0.001
gamma BHC(lindane)	ND	0.001	0.001
heptachlor	ND	ND	0.001
aldrin	ND	ND	0.001
alpha endosulfan	ND	ND	0.001
beta endosulfan	ND	ND	0.001
4,4'-DDE	ND	ND	0.001
dieldrin	0.030	0.030	0.001
endrin	0.007	0.008	0.001
4,4'-DDD	ND	ND	0.005
2,4'-DDT	ND	ND	0.005
4,4'-DDT	ND	ND	0.005
alpha chlordane	ND	NS	0.001
gamma chlordane	ND	0.002	0.001
mirex	ND	ND	0.005

Notes: Location of sampling sites shown in Figure 6.

[a] Analyzed by the Ontario Ministry of the Environment for Gartner-Lee Associates on samples collected in April - May, 1980.

[b] RQL means Reliable Quantification Limit.

ND means the compound was searched for; if present, the amount is below the detection limit.

small amounts of alpha BHC, dieldrin and endrin were detected at Site 24. At Site 29, which is a borehole located farther from the landfill, trace amounts of lindane, beta BHC, and chlordane were detected in addition to those pesticides found at Site 24.

C5. CHEMICAL CONTENT OF BACKGROUND WATERS

The impact of the landfill on groundwaters can only be assessed by reference to background waters that have not been contaminated with leachate. The WRI researchers used tritium content as a means of determining the time at which precipitation occurred to produce a given groundwater. Before the period of atmospheric nuclear testing, starting in 1953, the tritium content of precipitation was less than 10 tritium units. Because of radioactive decay, the tritium content, of pre-1953 groundwaters is now less than 2 tritium units. On the other hand, groundwaters charged after 1953 generally contain 10-200 tritium units. Thus the tritium level in groundwaters 'labels' waters as either pre- or post-1953.

Most of the landfilling at the site occurred after 1953 and, therefore, groundwaters containing less than 2 tritium units would not be expected to be contaminated with leachate to any appreciable extent. Only the post-1953 groundwaters have the potential to contain contaminants originating from the landfill. Contaminants present in pre-1953 groundwaters, therefore, must originate from sources other than the landfill, presumably from bedrock. Also, post-1953 groundwaters which are sampled from sites that are some distance from and upgradient from the landfill, would also be expected to be free of landfill contaminants.

Table 19 presents chemical data on four groundwater samples that are believed to be natural background waters free of leachate contamination. Two of these, from boreholes at Sites 1 and 14, have a tritium content of 2 tritium units and, therefore, are 'old' waters pre-dating 1953. Also, the sites are distinctly upgradient from the landfill; Site 1 is on the west side of Upper Ottawa Street in a residential area, and Site 14 is north of Red Hill Creek and to the northeast of the landfill.*

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* The results reported in Table 19 for Site 1 are for a groundwater sampled at a depth of 34.6 metres. At nine metres, the groundwater is post-1953, but its aromatic hydrocarbon content is not significantly different from that of the groundwater sampled at the greater depth. This supports the assumption that groundwaters located at a distance to the west of the landfill are free of landfill sourced contaminants.

Table 19: Chemical Content Of Background Groundwaters

	Old Background Waters		New Background Waters	
Sampling Depth:	Site 1 34.6m	Site 14 31.7	Site 4 10.0m	Site 41 6.1m
Inorganics[a] parts per million (unless otherwise shown)				
tritium (tritium units)	2	2	62	70
pH[b]	6.70	6.06	6.98	7.44
conductivity[c]	112,000	150,000	3000	1247
TOC (total organic carbon)	36.6	4.2	32.9	15.0
calcium	11,500	16,400	345	183
magnesium	3150	4300	37	55
sodium	18,400	29,400	161	37
potassium	300	490	16	2
chloride	61,400	84,560	202	70
alkalinity ($CaCO_3$)	NR	45	231	343
sulfate	1200	1080	1360	310
fluoride	NR	NR	0.8	0.7
nitrate, as N	0.1	0.1	0.1	0.1
Kjeldhal nitrogen, as N	45	65	5.0	0.2
arsenic	0.001	0.001	0.001	0.030
cadmium	0.010	0.005	0.005	0.001
chromium	0.12	0.04	0.025	0.007
iron(total)	1.2	0.88	0.61	0.19
lead	0.06	0.09	0.03	0.01
manganese	1.6	1.10	0.05	0.03
selenium	0.001	0.001	0.001	0.03
zinc	0.08	0.04	0.01	0.27
Organics[d] parts per billion				
benzene	0.65	0.76	0.01	0.18
toluene	2.60	1.50	0.27	0.30
ethylbenzene	0.20	0.10	ND	0.09
p-xylene	0.67	0.14	0.03	0.22
o-xylene	0.26	0.09	ND	NR
chlorobenzene	ND	ND	ND	NR
naphthalene	0.27	0.10	0.04	0.11

Notes: Locations of sampling sites shown in Figure 6.

[a] All samples for inorganic analyses collected between May and December 1983 and analyzed for the Waterloo Research Institute by the Ontario Ministry of the Environment.

[b] Measured in pH units 0-14 (7 is neutral; below 7 is acidic; above 7 is alkaline).

[c] Measured in uohms/cm (us).

[d] Organics analyzed by Waterloo Research Institute using gas chromatography (GC) only.

ND means the compound was searched for; if present, the amount is below the detection limit.
NR means the presence or absence of the compound was not reported by the laboratory.

It is to be noted that these 'old' groundwaters gave high values for most inorganic parameters, even in comparison to concentrated leachate. The WRI researchers attributed this to the long time these waters have been in contact with bedrock. Also, these background waters were found to contain appreciable quantities of volatile aromatics, whose source it would seem can only be the hydrocarbon-containing shale zone of the bedrock.

The two other groundwaters identified as background waters in Table 19 are located at Sites 4 and 41, both situated to the west of the landfill. These sites are definitely upgradient of the landfill, and their groundwaters should be largely uncontaminated by leachate. They are post-1953 groundwaters, however, and the sites are located less than 200 metres from the landfill. Their identification as background waters, therefore, is not on as firm a basis as that of the pre-1953 groundwaters at Sites 1 and 14.

There is a remarkable difference in the concentrations of many of the inorganic species in the two types of background water, in some instances amounting to as much as one hundred-fold. The lower values for the 'new' waters is consistent with their shorter residence time in bedrock. Also, there is some indication that the 'new' waters contain somewhat smaller concentrations of volatile aromatics, although the differences may be too small to be significant. The one firm conclusion that can be reached that the so-called natural water in the vicinity of the landfill is of very poor quality.

D. RECOGNITION OF LEACHATE CONTAMINATION IN GROUNDWATERS

The question to be answered was whether or not the chemical content of groundwaters downgradient from the landfill is sufficiently different from background waters to permit the identification and mapping of a contaminated groundwater plume.

Table 20 shows the inorganic and GC organic analyses for groundwaters from six boreholes (Sites 39, 23, 40, 24, 27 and 28) located east and south of the landfill at distances ranging from 300 to 500 metres. These sites were selected because the hydrogeological study indicated that the plume was moving east towards Albion Falls. For comparison, results for two background waters (Sites 14 and 4) from Table 19 and a concentrated leachate (Site 15) are also shown.

It is clear that the inorganic data are unhelpful for the identification of landfill contamination; parameters such as conductivity, and calcium, magnesium, sodium and chloride concentration, vary widely depending on the age of the groundwater, while the concentrations of heavy metals are low, even in leachate.

Table 20: Comparison of Chemical Content of Background Groundwaters, Downgradient Groundwaters, and Leachate

	Background Waters		Downgradient Waters						Leachate	Drinking Water Criteria[a,b]
Sampling Depth	Old Site 14 31.7	New Site 4 10.0m	Site 39 18.9m	Site 23 8.4m	Site 40 18.1m	Site 24 8.1m	Site 27 23.5m	Site 28 5.9m	Site 15	
Inorganics[c] parts per million (unless otherwise shown)										
tritium (tritium units)	2	62	NR	ND	27	1	20	4	NR	
pH[d]	6.06	6.98	6.16	6.70	6.70	7.62	7.06	6.94	7.86	6.5 to 8.5[a]
conductivity[e]	150,000	3000	110,000	64,000	124,000	30,600	89,000	10,000	25,900	-
TOC (total organic carbon)	4.2	32.9	31.3	100	98.6	9.4	NR	8.3	NR	5[a]
calcium	16,400	345	11,500	5500	12,800	NR	8100	813	79.0	
magnesium	4300	57	3150	1460	4750	NR	2600	265	86.0	
sodium	29,400	161	17,300	8700	19,600	3700	12,800	1180	4700	below 20[a,f]
potassium	490	16	270	156	297	71	212	25.0	135	
chloride	84,560	202	57,480	27,300	65,360	11,000	42,680	2906	4362	250[a]
alkalinity($CaCO_3$)	45	251	71	298	128	284	80.8	277	9130	30-500[a]
sulfate	1080	1360	838	1325	880	1500	890	1110	130	500[a]
fluoride	NR	0.8	NR	NR	NR	0.55	NR	0.70	6.6	1.2 (2.4)[a,g]
nitrate, as N	0.1	0.1	0.1	0.4	0.1	0.2	0.1	0.1	0.50	10[a]
Kjeldhal nitrogen, as N	65	5.0	40	NR	NR	10	55	12.5	1600	0.15[a]
arsenic	0.001	0.001	0.002	0.001	0.001	0.08	0.002	0.014	0.029	0.05[a]
cadmium	0.005	0.005	0.005	0.005	0.002	0.005	0.005	0.005	0.010	0.005[a]
chromium	0.04	0.025	0.45	0.04	0.07	0.04	0.76	0.03	0.82	0.05[a]
iron(total)	0.88	0.61	16	0.24	0.32	0.09	0.20	0.5	7.1	0.3[a]
lead	0.09	0.03	0.04	0.03	0.04	0.03	0.04	0.03	0.10	0.05[a]
manganese	1.10	0.05	2.20	0.35	0.92	0.31	0.38	0.08	0.16	0.05[a]
selenium	0.001	0.001	0.001	0.001	0.001	0.001	0.002	0.001	0.004	0.01[a]
zinc	0.04	0.01	0.18	0.06	0.15	0.12	0.09	0.03	0.47	5[a]
Organics[h] parts per billion										
benzene	0.76	0.01	5.95	1.03	1.62	0.38	4.3	0.12	26.96	1.0[b]
toluene	1.50	0.27	58.7	1.04	2.82	3.40	60.8	0.13	241.92	50.0[b]
ethylbenzene	0.10	ND	0.22	0.22	0.23	0.30	3.40	ND	74.04	50.0[b]
p-xylene	0.14	0.03	0.64	0.55	0.68	0.51	0.60	0.06	191.12	50.0[b]
o-xylene	0.09	ND	0.23	0.4	0.66	0.23	0.60	ND	123.17	50.0[b]
chlorobenzene	ND	ND	ND	ND	0.04	ND	0.01	ND	NR	20.0[b]
naphthalene	0.10	0.04	0.19	1.95	0.31	0.83	0.20	0.03	60.32	10.0[b]

Notes: Location of sampling sites shown in Figure 6.

[a] Ontario Ministry of the Environment Drinking Water Objectives (where avalible).
[b] New York State Proposed Drinking Water Toxics Standards, January, 1985 (where available).
[c] All samples for inorganics analysis collected between May and December, 1983 and analyzed for the Waterloo Research Institute by the Ontario Ministry of the Environment.
[d] Measured in pH units 0-14 (7 is neutral; below 7 is acidic; above 7 is alkaline).
[e] Measured in µmhos/cm (us).
[f] Not specified but 20ppm is defined as a warning limit.
[g] Where fluoridation is practiced, a maximum concentration of 1.2 mg/L is recommended and 2.4 mg/L in natural water.
[h] Organics analyzed by Waterloo Research Institute using gas chromatography (GC) only.

ND means the compound was searched for; if present, the amount is below the detection limit.
NR means the presence or absence of the compound was not reported by the laboratory.

With two exceptions, the concentrations of organics also are at the same general level in downgradient groundwaters as in background waters. At Sites 39 and 27, however, the concentration of benzene and toluene is from 10 to 100 times higher than that of background waters and only four times less than that of concentrated leachate. On the other hand, the groundwaters from boreholes at Sites 23, 40 and 24, located between Sites 39 and 27, show background concentrations of these two hydrocarbons.

It is difficult to interpret these findings. It is possible that there are channels of leachate contaminated groundwater moving through the fractured rock at Sites 39 and 27 and not at the sampled locations in between. Alternatively, the results may simply be a reflection of the concentration of benzene and toluene present in the bituminous shale at these sampling points.

Since no single chemical species served as a suitable indicator of landfill contaminants in groundwater, the WRI developed a battery of 14 tests to apply to this problem: three were based on inorganic species; four used the GC data for volatile organics; and seven the GC-MS data for extractable compounds. Each groundwater was then scored in terms of probable leachate impact. While this more systematic approach helped to identify the more highly contaminated groundwaters, the location of these contaminated sites was not readily interpretable in terms of their hydrogeological setting.

There are three reasons why this study of groundwater chemistry failed to identify landfill contaminated groundwaters and, therefore, to map a leachate groundwater plume. First, the natural background waters themselves are highly contaminated by many of the substances (e.g., chloride, iron, aromatic hydrocarbons, etc.) that have served as suitable indicators in similar studies in the past. Second, the level of contamination of even concentrated leachate from boreholes on the landfill itself or from seeps is not high. As a result, dilution rapidly reduces the contamination to levels that are difficult to distinguish from the background waters themselves. Finally, the pattern of flow in the fractured bedrock is extremely complex, so that even if landfill contamination of groundwaters were high, it would be difficult to satisfactorily map a plume without an even larger number of sampling sites.

E. SEVERITY OF LANDFILL—LEACHATE CONTAMINATION

Although groundwater is not a source of drinking water in the area in which the landfill is located, it is useful to compare levels of contamination with drinking water quality criteria. This is shown in Table 17, which reports the results of the

GC-MS analysis of organics and in Table 19, which reports inorganic parameters and the results of the GC analysis of volatile organics. (A more comprehensive list of sampling sites and contaminants is shown in Tables 1, 2, 3 and 4 in Appendix 4.)

It is clear that both upgradient background groundwaters and downgradient waters exceed water quality criteria for many inorganics and, in some sites, for benzene, toluene, phenols, phthalates and tetrahydrofuran. In addition, there are other organic compounds, (e.g., benzothiazole), for which drinking water standards have not been established but whose concentration probably exceeds a safe level. Higher levels of contamination by organics were usually found in groundwater close to the landfill; only very infrequently did concentrations at distant sampling sites exceed accepted water quality standards. Furthermore, as discussed in the preceding section, organic contaminants in groundwaters at distant sites were only occasionally in higher concentration than in 'old' natural background waters.

WRI researchers calculated the total flux of specific contaminants entering the environment from groundwater using the data on the rate of leachate production obtained in the hydrogeological study and contaminant concentration in that leachate. As reported in Chapter 6, estimates of leachate production range from 2.1 to 21 litres per second. Contaminant concentrations vary widely depending on the sampling site. In Table 21 are shown the maximum flux of selected contaminants in kilograms per year calculated using the higher value of 21 litres per second for the rate of leachate production and the maximum concentrations observed by WRI for onsite leachate.

Table 21: Calculated Maximum Flux of Selected Contaminants Entering Groundwaters at the Landfill Site

Contaminant	Maximum Flux (kg/year)
Boron	79,000
Arsenic	19
Lead	63
Benzene	18
Dichlorobenzene	6
Phenol	60
Di-butyl Phthalate	5
Benzothiazole	17

Given the history of landfilling at this site, these values are surprisingly low. Higher concentrations of contaminants, especially organics, might have been expected.

The WRI researchers have speculated on some reasons for the lack of organic contamination. One possibility, of course, is a low organic content of the wastes or the effectiveness of burning such wastes. Another is that over the years there has been a biodegradation and chemical transformation of contaminants in the landfill and along groundwater flow paths. It is possible also that there has been limited leaching of compounds of low water solubility and that compounds of high solubility have already been transported beyond the borehole network. The WRI group believe the latter to be unlikely given the hydrogeological setting. Finally, the WRI group addressed the suggestion that has sometimes been made that dense, water-insoluble organics, such as PCBs, might migrate downward to form a discrete phase beneath the landfill. It was concluded that this is highly unlikely. Such halogenated compounds were never found above trace levels in any groundwaters, including groundwaters immediately beneath the site. This would indicate that they are not present in amounts sufficient to establish a dense organic liquid phase.

F. CONCLUSIONS

The leachate emanating from the Upper Ottawa Street landfill has resulted in only a slight deterioration in groundwater quality, reflecting the generally poor quality of the natural groundwaters in the area. The most serious contamination is limited to within 100 metres of the landfill, with some contamination in the 300-500 meter range east and south of the site. Nevertheless, dilution and dispersion with distance have greatly reduced landfill contamination concentrations to such an extent that they can be barely distinguished from background.

Since groundwaters are not used for drinking water or other purposes in the area, there does not appear to be a hazard to the public at the present time due to landfill-leachate contamination. On the other hand, there are many organic compounds present in the groundwaters whose identity has not been established. Furthermore, the possibility exists that there are compounds in the landfill which have not yet been released from their containers. If so, these constitute a possible future hazard to the public. This suggests the need for ongoing monitoring of groundwaters at the site.

References

1. J.A. Cherry, "Occurrence and Migration of Contaminants at Municipal Landfills on Sand Aquifers," in Environment and Solid Wastes, eds. C.W. Francis, S.I. Auerbach and V.A. Jacobs, (Boston: Buttersworth, 1983), pp. 127-147.

2. J.A. Cherry, J.F. Barker, R.J. Blackport, and J.E. Barbash, " Appendix A," Hydrogeological Investigations of the Upper Ottawa Street Landfill Site in Hamilton, Ontario (Final Report), Institute of Groundwater Research at the University of Waterloo, 1984.

3. Gartner Lee Associates Limited, Hydrogeological Study of Leachate and Gas Impacts (Stage 2) at the Upper Ottawa Street Landfill, Hamilton-Wentworth, September 1980.

4. Gartner Lee Associates Limited, Monitoring Program Report of the Upper Ottawa Street Landfill Site 1982-1984, Hamilton-Wentworth, January, 1985.

5. J. Hoefs, Stable Isotope Geochemistry (Berlin: Springer-Velay, 1980).

CHAPTER 8

CHEMICALS IN LANDFILL GAS AND SURROUNDING NEIGHBOURHOODS

TABLE OF CONTENTS

Page

A. INTRODUCTION 140

B. VOLATILE ORGANICS IN LANDFILL GAS 143

B1. METHODS 143

B1.1 Sampling 143
B1.2 Analysis 143

B2. FINDINGS 145

C. POLYCYCLIC AROMATIC HYDROCARBONS (PAHs) IN LANDFILL GAS 148

C1. INTRODUCTION 148

C2. METHODS 148

C3. FINDINGS 151

D. VOLATILE ORGANICS IN AMBIENT AIR 153

D1. INTRODUCTION 153

D2. TAGA ANALYSIS PROGRAM (SCIEX) 153

D2.1 Methods 153
D2.2 Findings 154

D3. GC-MS ANALYSIS PROGRAM FOR VOLATILE ORGANICS (Mann Testing Laboratories) 156

D3.1 Methods 156
D3.2 Air Surveys 156

E. POLYCYCLIC AROMATIC HYDROCARBONS (PAHs) IN AMBIENT AIR 161

E1. METHODS 161

E2. Findings 161

Page

F. ATMOSPHERIC DISPERSION OF LANDFILL GAS 163

G. MUTAGENICITY ASSAYS 168

G1. INTRODUCTION 168

G2. METHODS 168

G2.1 Landfill Gas 168
G2.2 Air Particulates 168

G3. FINDINGS 169

G3.1 Landfill Gas 169
G3.2 Air Particulates 169

H. COLLECTION AND FLARING OF LANDFILL GAS 169

H1. INTRODUCTION 169

H2. FEASIBILITY OF COLLECTING AND FLARING THE LANDFILL GAS 170

H3. COMBUSTION EFFICIENCY FOR TRACE ORGANICS 171

H3.1 Methods 171
H3.2 Findings 171

H4. EFFECT OF CONTINUOUS PUMPING 173

H5. CONCLUSIONS 173

References 175

List of Tables and Figures

Table		Page
22	Analyses of the Main Constituents in Landfill Gas	146
23	GC-MS Analyses of Landfill Gas for Volatile Organics	147
24	A Comparison of Landfill Gas Samples from the Same Sites at Different Times	149
25	GC-MS Analyses of Air at Various Distances from Gas Vents on the Landfill	150
26	GC-MS Analyses of Landfill Gas for Polycyclic Aromatic Hydrocarbons (PAHs)	152
27	Summary of Quantitative Results for the TAGA Analyses	155
28	GC-MS Analyses of Air in the Neighbourhood Close to the Landfill	157
29	Variations in GC-MS Air Survey Results on Successive Days	159
30	GC-MS Air Survey Results for Sampling over a Three Year Period	160
31	Analysis of Ambient Air for Polycyclic Aromatic Hydrocarbons (PAHs)	162
32	Estimated Emission Rates and Atmospheric Dispersion of Major Landfill-Sourced Contaminants	167
33	Concentrations of Trace Organics in Pre- and Post-Flaring Landfill Gas	172

Figure		Page
12	Location of Sampling Sites for Landfill Gases and Air in Surrounding Neighbourhoods	144
13	Annual Ground Level Concentrations (ug/m^3) due to Unit Emission Rate (lg/s) from Source - Total Landfill Area	165
14	Summer Ground Level Concentrations (ug/m^3) due to Unit Emission Rate (lg/s) from Source - Total Landfill Area	166

A. INTRODUCTION

The Study Committee identified air as the most likely route of exposure to landfill contamination for area residents. Of particular concern are aromatic and chlorinated hydrocarbons, some of which have mutagenic and carcinogenic properties.*(1)

The detection and quantification of landfill contaminants in air is much more difficult than in leachate. First, there is the problem of the selection of appropriate sampling sites. Changing atmospheric conditions, including highly variable localized air currents, make it very difficult to know the extent to which the chemical content of individual samples is indicative of landfill-sourced air contamination.

The Upper Ottawa Street landfill dump, like other landfills, is a source of strong and unpleasant odours which are due largely to sulfur-containing compounds called mercaptans. These odours are sometimes taken to suggest evidence of a toxic hazard. However, since the nose can detect mercaptans at very low levels and since these compounds are not themselves highly toxic, they can be present at levels which create an exceedingly unpleasant and even nauseating smell without (otherwise) representing a direct risk to health. Furthermore, while the odours certainly indicate the release of landfill gas, the question of whether or not this gas carries with it unacceptable levels of unrelated and perhaps odourless toxic compounds can be answered only by chemical analysis of the ambient air.

A second and related factor is the rapid dilution of compounds escaping from the landfill coupled with high background levels of many of the same compounds in industrial cities like Hamilton.(2) For example, concentrations of aromatic hydrocarbons may be significant within the landfill and inside gas vents, while at the perimeter of the site and in the residential bordering areas the contribution of the landfill may be small compared to the contribution of other sources such as motor vehicles. The problem is not unlike that encountered with groundwaters at the site where it is difficult to distinguish between contamination that is caused by the landfill and that caused by other sources.

Finally, technical problems associated with the collection of air samples have not been completely resolved.(3,4) This is reflected in the fact that EPA has adopted an approved protocol and methodology for water analysis, but similar guidelines are still being developed for the analysis of organic compounds in ambient air.

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* All aromatic hydrocarbons contain rings consisting of six carbon atoms (e.g., benzene). The term polycylic aromatic hydrocarbons (PAHs) denotes compounds in which two or more fused six-membered rings are present (e.g., phenanthrene).

Prior to the initiation of the Committee's chemical analysis program, the Ontario Ministry of the Environment (MOE) carried out GC-MS analyses of vent gases and of off-landfill air samples.(5) These analyses, while intended to be qualitative, provided a rough indication of concentration levels. Identification by EPA/NIH library matching was tentative since pure standards were not used.

The majority of the compounds observed by the Ontario Ministry of the Environment in gas vent samples belonged to the following classes:

aliphatic petroleum hydrocarbons
alkyl benzenes
naphthalene and higher PAHs
esters, alcohols and ketones
terpenes and other natural products
phthalates

In addition, the presence of dichlorobenzene and either nitrocresol or nitroanisole was indicated.

In the vent gases, concentrations of individual PAHs, other than naphthalene and alkylnaphthalenes, were usually less than 2 $\mu g/m^3$. The total PAHs, including naphthalene and alkylnaphthalenes, were in concentrations of less than 50 $\mu g/m^3$.*

The off-landfill samples were collected by the MOE at a number of nearby sites both upwind and downwind of the landfill and, for comparison, at a more distant site located at the Fennel Avenue Health Unit, which is three kilometres northwest of the site. The majority of the compounds detected were alcohols and ketones. Alkylbenzenes, naphthalene and alkylnaphthalenes were found at several sites, including Fennel Ave. The PAHs (9H-fluorene, phenanthrene and/or anthracene) were observed in one sample collected downwind of the landfill at Stone Church Road. The total PAH concentration in this sample, including the naphthalenes, was of the order of 1 $\mu g/m^3$.**

---

* Concentrations reported by the MOE are only approximate (within a factor of ten) since standards were not used and the analytical method was at an early stage of development. Since most of the PAHs in air are probably not present as gases but rather are adsorbed on particulates, their concentration is expressed on a wt./vol. rather than on vol./vol. basis. For naphthalene, 1 $\mu g/m^3$ corresponds to 0.2 ppb.

** It is worth noting that this downwind sample was collected at the time when some 1400 tons per day of steel wastes were being placed on the landfill as part of the cover materials. Since these wastes are known to contain PAHs, they may have contributed to the PAHs detected by the MOE at this downwind site.

The absence or very low concentrations of PAHs in samples collected from off-landfill sites is to be expected since the concentrations within the vents themselves were not high and the escaping gas would be rapidly and extensively diluted.*

Analyses for metals were also carried out by the MOE between January 1981 and January 1982 using high-volume samplers to collect suspended particulates. Concentrations were found to be low, rarely exceeding the MOE criteria for particulates, and with little difference between upwind and downwind sites.(6)

The Study Committee retained two laboratories for the analyses of organics in samples taken from the landfill and the surrounding neighbourhoods. The first was Sciex (now a division of MDS Health Group Ltd., Toronto) which had recently developed a new mobile mass spectrometer, known as the TAGA 3000, which is particularly sensitive in detecting low concentrations of organic compounds in air.

The second company selected for gas analysis was Mann Testing Laboratories Ltd. (MTL) which had completed leachate analysis for the Committee prior to its gas analysis work. A number of analytical programs using conventional GC-MS were carried out by MTL: analyses for volatile organic compounds in landfill gas within, and a metre from, the gas vents; analyses of PAHs within vents; analyses for volatile organics in ambient air at sites located near the landfill; and analyses for targeted PAHs at similar locations.

An atmospheric dispersion study of landfill gas was conducted by CJB Associates Inc. This study used meteorological data and information on sources of emissions of landfill gas to model mathematically the concentration of pollutants in proximity of the site.

In addition to chemical analyses, the Committee also retained Mutatech Inc. to carry out mutagenic assays on landfill gas and particulates. The mutagenicity assays are biological, not chemical, tests and are included in this chapter on chemical results for the readers' convenience. The objectives of the mutagenicity tests, which consisted of Ames assays, were to determine whether or not gas and air particulates emanating from the landfill contain mutagens and, if they did, to estimate the levels of activity present. An important question to be addressed by this work was whether the levels of mutagens in the air in residential areas surrounding the landfill are higher than those in residential areas of Hamilton distant from the site.

In parallel with these studies, the Committee investigated the feasibility of collecting and burning the landfill gas.(7) Given the size of the landfill, it can be expected that large amounts of methane gas are being formed by the decomposition of domestic garbage, and that this gas may carry with it potentially toxic vapours originating largely from co-deposited industrial wastes.

---

* The Committee in its quantitative work observed that constituents of vent gases are diluted by a thousand times only a metre from the mouth of a vent (Table 25).

The Committee retained Conestoga-Rovers (CRA) to study the feasibility of collecting and flaring the landfill gas. The analytical work for this study was performed by MTL.

The locations of the sampling sites in proximity to the landfill, which are discussed in this Chapter, are shown in Figure 12. A detailed description of all sampling sites, including the offsite control locations not shown in Figure 12, is contained in Appendix 5.

B. VOLATILE ORGANICS IN LANDFILL GAS

B1. METHODS

B1.1 Sampling

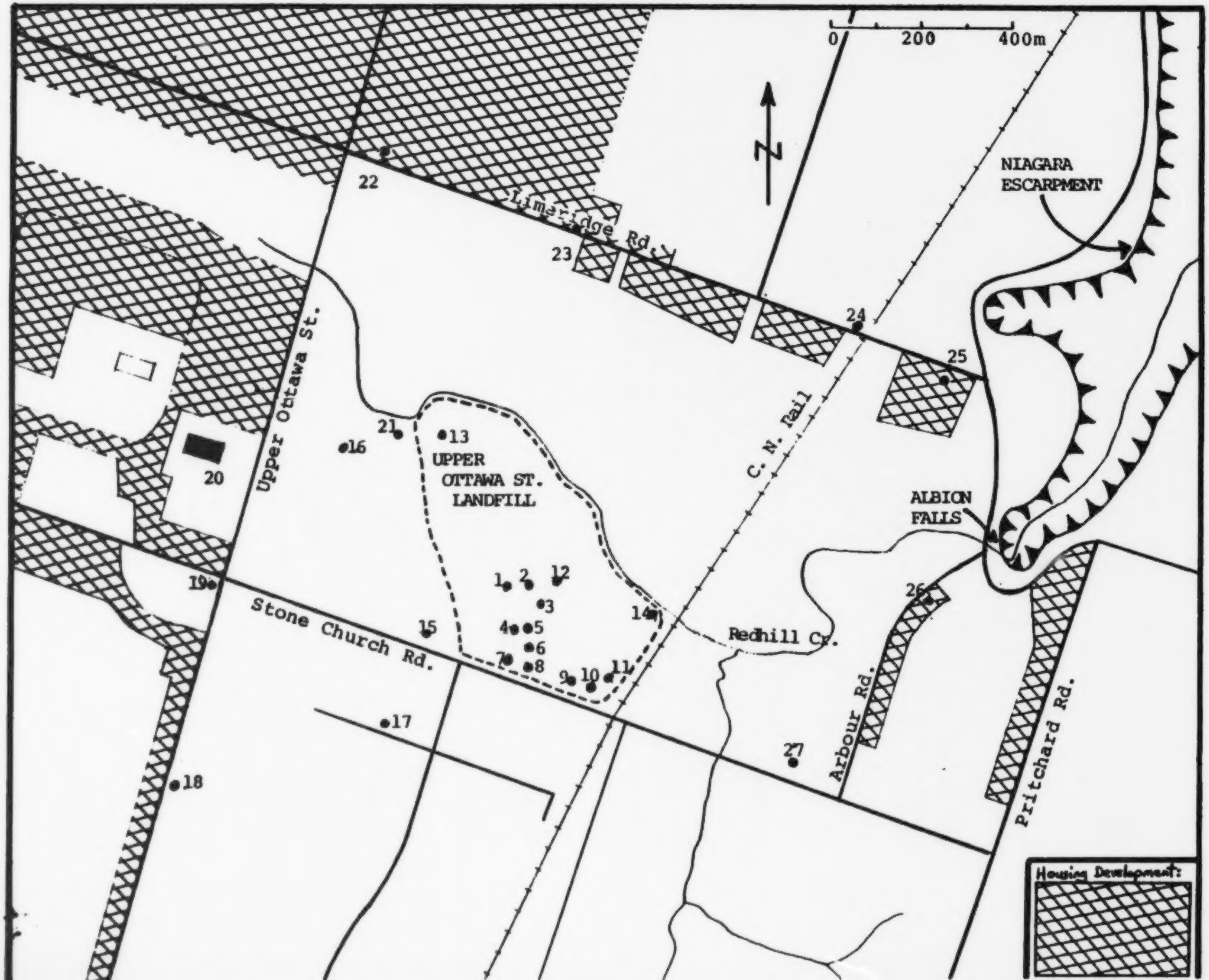
Sampling of landfill gas within gas vents was carried out using teflon air bags of one to five litre capacity. The bags were filled either 'actively' by inserting a teflon tube one metre into the vent and withdrawing a gas sample using a small electric pump or, 'passively', by attaching the inlet valve of the bag to a copper tube inserted in a rubber stopper used to seal off the vent. The air bags are particularly suitable for sampling gas containing high concentrations of volatile organics.

Sampling at sites in close proximity (0.6 to 1.2 m) to the vents was carried out by pumping a measured amount of air through a small cartridge containing a multi-layered adsorbent of tenax/ambersorb/charcoal, commonly referred to as a Tenax tube. The advantage of this method is that large volumes of air can be sampled, which makes it especially suited for analyses of organics at trace levels (ppb). On the other hand, some highly volatile non-polar compounds are not quantitatively retained if very large sampling volumes are employed. There is also the problem that a few compounds have a tendency to undergo chemical change on adsorption or thermal desorption. Nevertheless, the Tenax adsorption tubes are becoming recognized as generally effective for the sampling of low concentrations of most volatile organic compounds.

B1.2 Analysis

Samples collected on Tenax were thermally desorbed and the released organics were separated by gas chromatography and analyzed by mass spectrometry. In the case of air bag samples, a small aliquot of gas (usually 5 ml.) was injected into the inlet valve of the GC-MS instrument.

FIGURE 12: Location of Sampling Sites for Landfill Gas & Surrounding Neighbourhoods (See Appendix 5 for description)


0
200
400m
N
NIAGARA ESCARPMENT
ALBION FALLS
Limeridge Rd.
C. N. Rail
Redhill Cr.
Arbour Rd.
Pritchard Rd.
Upper Ottawa St.
Stone Church Rd.
UPPER OTTAWA ST. LANDFILL
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Housing Development:

Quantification was accomplished using as an external standard a mixture containing a known concentration of each of the pure targeted compounds. The targeted list was compiled on the basis of previous findings of the analysis of air (MOE and Sciex) and water (MTL).

In the quantification of targeted compounds, observed mass spectra were matched with the EPA library of spectra and the results examined for the presence of other compounds of possible concern.

In addition to analyses for trace organics, air bag samples of gas collected from within vents were analyzed by gas chromatography for major constituents, methane, carbon dioxide, oxygen and nitrogen. This established the extent to which the landfill gas had been diluted by air.

B2. FINDINGS

The results of the GC analyses for the major constituents of landfill gas sampled from within vents at Sites 1, 2, 4, 5, 7 and 13 are shown in Table 22.(9)

The landfill gas collected from the gooseneck vent at Site 7 was found to be highly diluted by outside air. This vent extended into a shallow French drain approximately one metre below the surface of the landfill. Samples from the other vents, which go deeper into the landfill, contained from 50 to 60 per cent methane and were less contaminated by oxygen and nitrogen and are, therefore, more representative of the gas generated within the landfill.

The results of the GC-MS analysis of targeted organic compounds in air bag samples of vent gases collected at Sites 1, 2, 4, 5, 6, 7, 10, 12 and 13 are shown in Table 23.(10) It can be seen that the concentrations of a number of compounds are in the ppm range. The compounds in highest concentration are the aromatic hydrocarbons, while the chlorinated hydrocarbons, dichloromethane, 1,1-dichloroethane, and 1,2-dichloroethene, were also found in a number of sites.

Site 1, an experimental test well drilled to a depth of 9.8 metres into the south slope of the landfill, appears to contain the largest number and highest concentration of compounds. The difference between pumping and passive collection appears to be small.

Sites 4 and 5 are gas probes located within a metre of each other; the former was installed to a depth of 3.1 metres and the latter to a depth of 7.6 metres. Depth of sampling would appear to have little effect at this location.

Sites 10 and 7 are gooseneck vents located several hundred metres apart on the south slope of the site at a depth of about one metre. Significantly higher concentrations were found for toluene, xylene and ethylbenzene at Site 10, which was sampled in December 1984, than at Site 7, which was sampled in October, 1985.

Table 22: Analyses of the Main Constituents in Landfill Gas[a]

	Site 1 %	Site 1[b] %	Site 2 %	Site 4 %	Site 5 %	Site 7[b] %	Site 13 %
methane	59.4	58.1	50.1	49.7	54.8	42.1	59.9
other hydrocarbons	0.1	0.2	0.04	0.05	0.09	0.03	0.03
carbon dioxide	27.0	27.4	26.3	21.0	24.5	22.1	26.2
oxygen	0.0	0.0	0.6	1.5	0.4	3.5	0.1
nitrogen	4.1	4.0	13.5	13.5	7.1	19.6	5.1
Total[c]	90.6	89.7	90.5	85.8	86.9	87.3	91.3

Notes: See location of sampling sites in Figure 12.

[a] All samples collected in air bags in October 1985 and analyzed by Mann Testing Laboratories using gas chromatography.

[b] These two samples were collected actively by pumping. All other samples were collected passively.

[c] The individual percentage values for methane, carbon dioxide, oxygen, and nitrogen may vary by plus or minus three per cent.

Table 23: GC-MS Analyses of Landfill Gas for Volatile Organics[a]
parts per million

	Site 1	Site 1[b]	Site 2	Site 4	Site 5	Site 6	Site 7[b]	Site 10[c]	Site 12	Site 13	RQL[d]
dichloromethane	ND	0.3	1.0	0.5	0.4	0.7	0.7	1.0	0.4	0.1	.06
chloroform	ND	ND	D	ND	ND	ND	ND	0.1	ND	ND	.05
1,1-dichloroethane	ND	ND	ND	ND	ND	ND	0.2	0.5	ND	ND	.06
1,2-dichloroethane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	.06
1,1,1-trichloroethane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	.05
1,2-dichloroethene	4.6	4.2	1.5	ND	ND	ND	ND	ND	ND	ND	.06
trichloroethene	ND	ND	ND	ND	ND	ND	BRQL	ND	ND	ND	.05
tetrachloroethene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	.05
benzene	3.0	3.5	0.9	1.6	1.2	0.5	0.6	1.0	2.7	0.2	.06
toluene	37.8	39.2	1.6	1.6	33.2	3.4	1.8	13.7	ND	0.3	.06
xylenes	26.6	35.9	8.4	15.5	14.6	3.8	1.9	27.7	9.9	BRQL	.06
ethylbenzene	7.8	11.1	2.3	5.4	5.2	1.9	0.5	7.8	4.9	BRQL	.06
C_3-benzenes	1.3	1.5	0.5	0.5	0.6	0.2	ND	NR	0.1	ND	.05
C_4-benzenes	1.9	1.1	ND	0.4	0.2	ND	ND	NR	ND	ND	.05
styrene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	.05
dichlorobenzene	ND	ND	ND	ND	BRQL	ND	ND	ND	ND	ND	.06
naphthalene	0.2	0.07	BRQL	BRQL	BRQL	ND	ND	NR	ND	ND	.06
acetone	ND	ND	0.5	0.4	1.5	1.9	35.1	0.5	1.6	ND	.07
benzaldehyde	ND	ND	ND	ND	ND	ND	ND	NR	ND	ND	.06
diethyl ether	ND	ND	1.8	2.7	ND	2.9	0.2	NR	1.7	ND	.07
THF	D	D	D	D	D	D	ND	NR	D	ND	
n-hexane	D	D	ND	D	D	D	BRQL	NR	BRQL	ND	

Notes: See location of sampling sites in Figure 12.

[a] Samples collected in air bags in October, 1985 and analyzed by Mann Testing Laboratories using gas chromatography-mass spectrometry.
[b] Samples collected by pumping. Samples collected passively at all other sites shown on this table.
[c] Sample collected in air bag in December 1984.
[d] RQL means Reliable Quantification Limit of the analytical method.

D means the compound was detected but the amount not determined.
BRQL means the compound was detected but Below Reliable Quantification Limit.
ND means the compound was searched for; if present, the amount is below the detection limit.
NR means the presence or absence of the compound was not reported by the laboratory.

The data were examined carefully for evidence that concentrations of constituents are changing with time. Two sets of findings for landfill gas sampled almost three years apart at Sites 1 and 2 are reported in Table 24.(11) Concentrations are from one to two hundred times greater for February 1983 compared to October 1985. Sampling on two occasions, however, does not establish a trend. Furthermore, different methods were used in the two sets of analyses.

The most striking observation in these analyses is the relatively low concentration of many compounds, including the chlorinated hydrocarbons, in what is essentially undiluted landfill gas. This is in contrast to what has been found at a number of other landfills on this continent.(12)

The results of the GC-MS analysis of Tenax tube air samples collected 0.6 and 1.2 metres from the openings of the goosenecks on the south slope of the landfill are reported in Table 25.(13) Note should be made of the fact that concentrations in this table are given in parts per billion, whereas in Tables 23 and 24 the concentrations are in parts per million for gas collected within the vents. As expected, there is extensive dilution of the landfill gas constituents, by as much as a thousand times, only a metre from the vent openings.

C. POLYCYCLIC AROMATIC HYDROCARBONS (PAHs) IN LANDFILL GAS

C1. INTRODUCTION

The presence of PAHs in leachate and in the steel wastes, which were mixed with the garbage deposited daily and used in the cover for the landfill, raises the question as to whether landfill gas might contain sufficient amounts of these substances to give rise to elevated concentrations in ambient air in the neighbourhoods surrounding the site. While the compounds of greatest concern would not be expected to be present in measurable quantities in the gaseous form because of their extremely low volatility, there is the possibility of their being adsorbed on particulates that are swept from the landfill by the venting gas. Furthermore, the lower molecular weight PAHs (up to four rings) are sufficiently volatile to be present in the gaseous form. It was decided, therefore, to attempt to determine the PAH content of the landfill gas itself and also to compare the concentrations of these substances in ambient air in the vicinity of the landfill with those at a control site. The PAH analyses of landfill gas are reported in this Section and that of ambient air in Section E.

C2. METHODS

The analysis of landfill gas for PAHs presents considerable technical difficulty and no established protocol has been developed. Since the higher molecular weight PAHs can be expected to be present in very low concentrations, large sampling volumes are required. This precludes the use of air bags and

Table 24: A Comparison of Landfill Gas Sampled from the Same Sites at Different Times
parts per million

	Site 1[a] (Feb.'83)	Site 1[b] (Oct.'85)	Site 2[a] (Feb.'83)	Site 2[b] (Oct.'85)	RQL[c]
benzene	NR	3.0	5.0	.89	.06
toluene	203	37.8	185	1.6	.06
xylenes	63	26.6	63	8.4	.06
1,1,1-trichloroethane	6.9	ND	1.3	ND	.05
tetrachloroethene	0.35	ND	0.18	ND	.05

Notes: See location of sampling sites in Figure 12.

[a] Samples collected passsively in air bags and analyzed by gas chromatography (GC) by Mann Testing Laboratories.
[b] Samples collected passively in air bags and analyzed by gas chromatography-mass spectrometry (GC-MS) by Mann Testing Laboratories.
[c] RQL means Reliable Quantification Limit of the analytical method.

ND means the compound was searched for; if present, the amount is below the detection limit.

NR means that the presence or absence of the compound was not reported by the laboratory.

Table 25: GC-MS Analyses of Air At Various Distances from Gas Vents on the Landfill[a]
parts per billion

	0.61 metres from vents[b]	1.2 metres from vents[c]	1.2 metres from vents[d]
dichloromethane	12.6	6.1	1.5
chloroform	2.0	0.8	1.1
1,1-dichloroethane	ND	ND	ND
1,2-dichloroethane	ND	ND	ND
1,1,1-trichloroethane	ND	ND	ND
1,2-dichloroethene	ND	ND	ND
trichloroethene	T	T	ND
tetrachloroethene	ND	ND	ND
benzene	0.8	0.6	3.0
toluene	2.7	1.4	16.4
xylenes	0.6	0.5	1.0
ethylbenzene	0.1	0.1	0.2
C_3-benzenes	0.1	0.2	T
C_4-benzenes	ND	T	ND
styrene	T	ND	ND
1,3-dichlorobenzene	1.0	0.7	ND
naphthalene	0.1	0.1	ND
acetone	17.1	10.2	19.9
benzaldehyde	NR	NR	ND
diethyl ether	3.5	1.8	ND

Notes:

[a] Sampled by Tenax tube and analyzed by GC-MS at Mann Testing Laboratories.

[b] Sampled in August 1984 at a distance of 0.61 metres downwind by walking in front of the line of landfill vents located north of Stone Church Road between Site 11 and to the west of Site 7. (see Figure 12)

[c] Sampled in August 1984 at a distance of 1.2 metres downwind by walking in front of the line of landfill vents located north of Stone Church Road between Site 11 and to the west of Site 7. (see Figure 12)

[d] Sampled in November 1984 at a distance of 1.2 metres downwind by walking in front of the line of landfill vents located north of Stone Church Road between Site 11 and to the west of Site 7. (see Figure 12)

All reported values below 1 ppb are semiquantitative; actual amounts present are unlikely to exceed the values reported and are less than 1 ppb.

T means detected but not quantified; concentrations are well below 1 ppb.
ND means the compound was searched for; if present, the amount is below the detection limit.

necessitates long pumping times using the adsorption tube sampling method. On the other hand, the lower molecular weight PAHs have a tendency to 'break through' the adsorbent, especially when sampling volumes are large, since the volatile organics, such as toluene and xylenes, which are present in relatively high concentrations in the landfill gas, cause saturation of the adsorbent.

The sampling method devised by Mann Testing Laboratories for this analysis involved pumping landfill gas at a rate of two litres per minute through an adsorption train consisting of a silver membrane filter followed by two Orbo-43 tubes.* The second sorption tube served as a check for 'break through'. Sampling volume was 720 litres. The filter was injected with deuterated standards for identification and quantification purposes.

The contents of the filter and sorption tubes were extracted with dichloromethane followed by filtration and concentration. The extracts from the filter and the first sorption tube were combined and analyzed separately from the extract from the second tube. Quantification of the PAHs was achieved by comparison of the mass spectra and peak intensity of the sample to that of the deuterated samples. In the case of 'break through' of the deuterated standards, the quantification was based on external standards. (See page 76 of Chapter 5 for a detailed explanation of these methods.) The lower limit of detection was estimated to be 10 ng/L.

C3. FINDINGS

The results of the PAH analyses of landfill gas emitted from the test well at Site 1 are shown in Table 26.(14) Concentrations are reported in ng/L and in ppb (bracketed numbers). The ppb values are calculated on the assumption that the PAHs are present in the landfill gas entirely in the gaseous form. While this would not be the case for PAHs adsorbed on particulates, concentrations expressed in ppb permit a comparison with the concentrations of the volatile organics which have been expressed in ppm or ppb units in previous tables. It can be seen that for the compounds naphthalene to fluoranthene, 'break through' from the first sorption tube has been extensive. Undoubtedly, a considerable amount of each of these compounds has passed through both tubes. Consequently, the amounts reported represent lower concentrations in comparison to the actual amounts present in the landfill gas. It is worth noting, however, that the total concentration of naphthalene shown in Table 26 agrees fairly closely with that found by the Tenax tube method for volatile organics and shown in Table 23.

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* Orbo-43 is the trade name for the sorbent tube used in this experiment. The type of sorbent material is a porous styrene-divinylbenzene co-polymer similar to XAD -2.

Table 26: GC/MS Analyses of Landfill Gas for Polycyclic Aromatic Hydrocarbons (PAHs)[a] in ng/L and (parts per billion)[b]

	First Orbo Tube + Filter		Second Orbo Tube	
	ng/L	(ppb)	ng/L	(ppb)
naphthalene	419.5	(73.4)	515.9	(90.3)
biphenyl	94.7	(13.8)	621.3	(90.4)
acenaphthylene	119.7	(17.6)	1048.8	(154.6)
fluorene	86.4	(11.7)	403.8	(54.5)
phenanthrene	175.9	(22.1)	126.9	(16.0)
anthracene	4.9	(0.6)	21.9	(2.8)
fluoranthene	5.4	(0.6)	8.8	(2.8)
pyrene	1.7	(0.2)	ND	
benzo(a)anthracene	ND		ND	
chrysene	ND		ND	
benzo(k)fluoranthrene	ND		ND	
benzo(a)pyrene	ND		ND	
dibenzo(a,h)anthracene	ND		ND	

Notes:

[a] Sampled from Site 1 (see Figure 12) with two connected tubes containing Orbo-43 sorbent and analyzed by quantified GC-MS for target PAHs by Mann Testing Laboratories.

[b] Values of ng/L can be converted to ppb by volume using the following formula, provided it is assumed the compound is in the gaseous phase:

$$\text{ppb} = \frac{\text{ng/L} \times 22.4}{\text{molecular weight}}$$

For example, for benzo(a)pyrene, which has a molecular weight of 252:

$$1 \text{ ng/L} = \frac{1 \times 22.4}{252} = 0.089 \text{ ppb}$$

ND means the compound was searched for; if present, the amount is below the detection limit.

None of the targeted higher molecular weight PAHs, benzo(a)anthracene to dibenzo (a,h)anthracene, shown in Table 26 was observed within the detection limit of about 10 ng/L (approximately one ppb). The fact that the concentration of these higher PAHs in the landfill gas itself is below one ppb strongly indicates that the landfill is making a negligible contribution to the concentration of the higher PAHs in ambient air in the neighbourhood of the landfill site. This is confirmed by the results of the analyses of PAHs in ambient air which are reported in Section E.

D. VOLATILE ORGANICS IN AMBIENT AIR

D1. INTRODUCTION

The first air analysis program commissioned by the Study Committee was caried out by Sciex Ltd. using their TAGA 3000 and 6000 mass spectrometers. This was followed by extensive air quality surveys by Mann Laboratories using conventional GC-MS methodology. The latter proved to be much more satisfactory for the situation presented by the Upper Ottawa Street landfill, namely, the presence of low concentrations of a very large number of compounds of unknown identity.

D2. TAGA ANALYSIS PROGRAM (SCIEX)

D2.1 Methods

The first stage of the Sciex work involved using the TAGA 3000 instrument to identify tentatively the many compounds present in the air in the vicinity of the landfill.(15)

The limitation of the TAGA 3000 technology is that several different compounds can produce molecular ions having the same M/Z value so that it is not possible to establish which of the several possibilities is actually present in the sample being analyzed. For example, in the air quality survey a molecular ion having M/Z of 74 was detected near the landfill. Substances that might have given this value include butyl alcohol, diethyl ether and dimethylnitrosamine. Of these, the first is an industrial solvent, the second was formerly widely used (at high concentrations) as an anesthetic and the third is a powerful carcinogen. Obviously, the TAGA 3000 data may have indicated the presence of a potentially serious problem but additional information on the true identity of the compound was needed to assess whether or not a hazard exists. On further analysis this compound turned out to be butyl alcohol.

In the second stage, verification was accomplished using the TAGA 6000 MS-MS instrument. This double mass spectrometer first separates charged molecular ions (parent ions) from one another and, in a second stage, fragments these ions to produce a complex fragmentation pattern (fingerprint) which is compared with that produced under similar instrument conditions by pure commercial samples of each of the selected compounds. Finally, the Sciex 6000 instrument was used to quantify the few compounds whose identity had been verified.(16)

Sampling locations in the Sciex work included sites upwind and downwind of the landfill; a residential control neighbourhood on the west mountain; locations in the industrial and downtown areas of Hamilton; and sites upwind and downwind of a domestic landfill in Ancaster.

D2.2 Findings

In their qualitative work, Sciex detected and tentatively identified 273 compounds. On the basis of detailed toxicological assessment, the Committee selected 31 for further investigation. Where various identities were possible, worst case assumptions were made.

Further analysis (the verification stage) confirmed the identity of only five of the 31 selected compounds of possible toxicological concern tentatively identified in the qualitative work. These were acrylic acid, phenol, cresols, xylenols and methyl pyridine. The identification of the pesticide carbaryl was inconclusive, but in planning for subsequent quantitative work it was assumed to be present. The remaining 24 compounds were found to correspond to compounds that were judged to be of low toxicity (e.g., the compound which in the worst case in the first stage qualitative work could have been dimethylnitrosamine turned out, in fact, to be butyl alcohol).

The results of the quantitative analysis of the six confirmed compounds are presented in Table 27. It can be seen that these compounds were present at all sites sampled and occurred upwind as well as downwind of the landfill. Further, with the exception of acrylic acid, they were found at much higher levels elsewhere than at the landfill.

During the summer of 1981, Sciex also carried out for the Ontario Ministry of the Environment qualitative surveys of gases emitted from vents on the landfill using the TAGA 3000.(17) The results were similar to those found in the TAGA 3000 analyses commissioned by the Study Committee: a large number of compounds detected but with only very tentative identification.

The Sciex work produced, in the end result, the verified identification and quantification of only a few chemicals. This is the result of the limitations in applying to this kind of study the TAGA technology at this stage in its development, the low concentrations of most pollutants, and the complex chemical nature of the landfill.

In addition to the air surveys described above, Sciex subcontracted analyses of chlorinated compounds to Wellington Environmental Consultants during the summer of 1981, because the TAGA 3000 was not equipped at the time to detect this class of compounds.(18) Wellington's results, using electron capture-gas chromatography (EC-GC) indicated that only a very small amount of chlorinated

Table 27: Summary of Quantitative Results for the TAGA Analyses[a]
parts per billion

1981 Survey

	Upper Ottawa Landfill				
	Site 20[b]	Site 21[b]	Site 24[c]	Site 19[b]	Site 26[c]
methylpyridine	0.01	0.008	0.02	0.02	0.01
carbaryl	0.002	0.001	0.02	0.02	0.01
acrylic acid	1.22	1.37	3.49	4.72	3.16
phenol	0.15	0.04	0.15	0.23	0.11
cresols	0.001	0.001	0.005	0.007	0.004
xylenols	0.5	0.35	1.11	1.25	0.95

1982 Survey

	Upper Ottawa Landfill		Ancaster Landfill		Other Areas in Hamilton Distant from the Upper Ottawa Landfill						
	Site 28[b]	Site 19[c]	Site 29[c]	Site 30[b]	Site 31	Site 32	Site 33	Site 35	Site 36	Site 37	Site 34
methylpyridine	0.22	0.12	0.07	0.09	0.1	0.12	0.01	3.17		0.01	0.63
carbaryl	ND	0.07	ND	0.05	ND	ND	0.03	0.20	ND	ND	0.10
acrylic acid	0.74	0.87	0.38	0.43	0.80	0.42	0.68	3.60	ND	ND	2.22
phenol	0.15	0.1	0.08	0.05	0.07	0.06	0.22	1.29	ND	0.33	1.28
cresols	0.004	0.003	ND	ND	0.003	0.002	0.003	0.02	ND	ND	0.29
xylenols	0.4	0.34	0.26	0.25	0.65	0.46	0.94	1.94	ND	ND	44.34

Notes:

[a] Location of sampling sites are shown in Figure 12.
[b] This site was downwind during sampling.
[c] This site was upwind during sampling.

ND means the compound was searched for; if present, the amount is below the detection limit.

organic compounds was present in the landfill vent gases.* By the summer of 1982, the TAGA instrument had been adapted to monitor chlorinated hydrocarbons and was applied to the problem. No chlorinated hydrocarbon was detected down to the detection limit of one part per billion.

D3. GC-MS ANALYSIS PROGRAM FOR VOLATILE ORGANICS (Mann Testing Laboratories)

D3.1 Methods

The program of ambient air analysis conducted by Mann Testing Laboratories, which began in the fall of 1982, was designed to incorporate what was already known about landfill contaminants from the air testing program carried out by MOE and Sciex and from the analyses of core, leachate and Red Hill Creek samples. Mann Testing Laboratories, therefore, had a basis for anticipating the types of compounds that could be expected.

Tenax tubes were used for all air sampling in the Mann air analysis program. Samples of air (volumes varied between 5 and 20 litres) were drawn through the sorbent at a pumping rate of 50 ml. per minute. Samples were thermally desorbed and the released organics were analyzed by conventional GC-MS. Quantification was accomplished using external standards of pure targeted compounds. The targeted list was compiled on the basis of previous air (MOE and Sciex) and water (Mann Testing Laboratories) findings. Matching of observed mass spectra with the EPA library of spectra served to identify other compounds of possible concern.

D3.2 Air Surveys

Air samples from a number of sites in close proximity to the landfill and at a control site were analyzed during a three year period, from November 1982 to July 1985. The results for one set of analyses, sampled on July 2, 1985, are reported in Table 28.(19) Sampling sites for this set were as follows:

Location of Site on Figure 12	Sample Designation	Distance from Mid-Point of Landfill in Metres
Site 18	Unsworth at Upper Ottawa St.	Upwind-739m.
Site 23	Limeridge Rd. at Lennox	Downwind-469m.
Site 20	Blessed Kateri Tekakwitha	School-419m.
Site 16	Public Works Yard	Public Works-236m.
Site 15	Fire Training Facility	Fire Hall-69m.
Site 31	Stonechurch Rd. at Garth St.	Control-6.5 kilometres west of the landfill.

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* No polychlorinated biphenyls (PCBs) were detected. One chlorinated pesticide, lindane, and a few chlorinated benzenes such as 1,3,5-trichlorobenzene were detected at the detection limit of one part per billion.

Table 28: GC-MS Analyses of Air in the Neighbourhood Close to the Landfill
parts per billion[a]

	Site 18 (Upwind)	Site 23 (Downwind)	Site 20 (School)	Site 16 (Works Yard)	Site 15 (Fire Hall)	Site 31 (Control)	Air Quality Criteria[b]
dichloromethane	ND	0.5	ND	1.1	0.2	ND	
chloroform	ND	ND	ND	ND	ND	ND	90[c]
1,1-dichloroethane	ND	ND	ND	ND	ND	ND	
1,2-dichloroethane	ND	ND	ND	ND	ND	ND	
1,1,1-trichloroethane	ND	ND	ND	ND	ND	ND	19,400[d]
1,2-dichloroethene	ND	ND	ND	ND	ND	ND	
trichloroethene	ND	ND	ND	ND	ND	ND	
tetrachloroethene	ND	ND	T	ND	ND	ND	
benzene	2.1	1.0	3.3	3.9	ND	3.4	950[d]
toluene	1.5	0.6	1.4	1.7	ND	1.3	490[d]
xylenes	T	ND	0.7	0.3	T	T	490[d]
ethylbenzene	ND	ND	T	T	T	ND	850[d,e]
C_3-benzenes	ND	ND	ND	ND	ND	ND	
C_4-benzenes	ND	ND	ND	ND	ND	ND	
styrene	T	ND	ND	ND	ND	ND	90[d]
dichlorobenzenes	ND	ND	T	ND	ND	ND	
naphthalene	ND	ND	0.4	0.2	T	ND	
acetone	2.6	ND	1.4	4.4	2.0	7.0	18,540[d]
benzaldehyde	1.2	ND	T	1.7	0.3	2.7	
diethyl ether	ND	ND	ND	ND	ND	ND	
n-hexane	ND	ND	ND	ND	ND	ND	

Notes: Location of sampling sites are shown in Figure 12.

[a] All samples collected by Tenax tubes on July 2, 1985, and analyzed by Mann Testing Laboratories.

[b] As established by the Ontario Ministry of the Environment, Feb.1, 1986 (24 hour average exposure for ambient air).

[c] Ministry of the Environment guideline.

[d] Ministry of the Environment standard.

[e] One hour average, rather than 24 hour average.

All reported amounts below 1 ppb are semiquantitative; actual amounts present are unlikely to exceed the values reported and are less than 1 ppb.

T means detected but not quantified; concentrations are well below 1 ppb.
ND means the compound was searched for; if present, the amount is below the detection limit.

It can be seen that only a few compounds, primarily aromatic hydrocarbons, were detected and that concentrations rarely exceed a few ppb. Chlorinated hydrocarbons were either not detected or were in concentrations of less than one ppb. Furthermore, concentrations of compounds detected were usually higher in the upwind and control samples than in the downwind samples. This suggests that other sources such as motor traffic may be the main source of contamination at offsite locations. Even at the public works yard and at the fire training facility, the numbers and concentrations of detected compounds were not significantly different from those of the control site.

It is important to emphasize that the results of a single analysis cannot be taken as indicative of the contamination levels over a period of time. The time-average concentrations of contaminants may be considerably different from those found in a single set of analyses.

Table 29 shows comparisons of findings at the same upwind (Site 18) and downwind (Site 23) sites on two successive days, July 2 and 4, 1985.(20) On July 2, there was a brisk wind and a rain storm in late afternoon. July 4 was a sunny day with a light to moderate breeze. It can be seen that there are significant differences. More compounds were detected and concentrations were usually higher on the less windy day. For example, naphthalene was found in both upwind and downwind samples on July 4, but was not detected on July 2. Also, there is an indication that downwind concentrations were slightly higher than upwind concentrations on July 4, the reverse of what was observed on the more windy day.

The results of air analyses at upwind, downwind, school and control sites over the three year period are shown in Table 30.(21) It can be seen that there is no clear trend in the concentration of compounds with time, either at the landfill or control sites. While there is some indication that contamination levels were lower in air sampled in 1984 and 1985 than in the preceding two years, there are clear exceptions to this. For this reason, we do not consider that a trend to lower levels has been demonstrated. In general, concentrations were as high or higher in samples collected at upwind and control sites, as in samples from downwind sites. Furthermore, the sampling dates which showed the higher concentrations at downwind sites usually showed the higher concentrations at other sites. This would suggest that it is the effect of climatic conditions on the concentration of pollutants having sources other than the landfill, e.g., motor traffic, which is mainly responsible for the range of values observed.

It is worth noting that the range of concentrations observed for the aromatic hydrocarbons in this study correspond fairly closely to those observed in other urban areas .(22)

Table 29: Variations in GC-MS Air Survey Results on Successive Days
parts per billion[a]

	July 2 (Upwind) Site 18	July 2 (Downwind) Site 23	July 4 (Upwind) Site 18	July 4 (Downwind) Site 23	Air Quality Criteria[b]
dichloromethane	ND	0.5	ND	ND	
chloroform	ND	ND	ND	T	90[c]
1,1-dichloroethane	ND	ND	ND	ND	
1,2-dichloroethane	ND	ND	ND	ND	
1,1,1-trichloroethane	ND	ND	0.5	0.4	19,400[d]
1,2-dichloroethene	ND	ND	ND	ND	
trichloroethene	ND	ND	ND	ND	
tetrachloroethene	ND	ND	ND	0.2	
benzene	2.1	1.1	9.5	12.7	950[d]
toluene	1.5	0.6	1.2	2.3	490[d]
xylenes	T	ND	1.0	1.5	490[d]
ethylbenzene	ND	ND	T	0.4	850[d,e]
C_3-benzenes	ND	ND	ND	ND	
C_4-benzenes	ND	ND	ND	ND	
styrene	T	ND	T	T	90[d]
dichlorobenzenes	ND	ND	ND	ND	
naphthalene	ND	ND	0.9	0.9	
acetone	2.6	ND	4.2	5.5	18,540[d]
benzaldehyde	1.2	ND	0.4	1.3	
diethyl ether	ND	ND	ND	ND	

Notes: Location of sampling sites shown in Figure 12.

[a] All samples collected by Tenax tube and analyzed by Mann Testing Laboratories.

[b] As established by the Ontario Ministry of the Environment, Feb.1, 1986 (24 hour average exposure for ambient air).

[c] Ministry of the Environment guideline.

[d] Ministry of the Environment standard.

[e] One hour average, rather that 24 hour average.

All reported values below 1 ppb are semiquantitative; actual amounts present are unlikely to exceed the values reported and are less than 1 ppb.

T means detected but not quantified; concentrations are well below 1 ppb.
ND means the compound was searched for; if present, the amount is below the detection limit.

Table 30: GC-MS Air Survey Results for Sampling over a Three Year Period[a]
parts per billion[a]

	Upwind					Downwind					School (Site 20)					Offsite Controls					
	Site 25	Site 22	Site 27	Site 2	Site 18	Site 17	Site 13	Site 22	Site 22	Site 23	Site 20					Site 38	Site 39	Site 40	Site 41	Site 31	Air Quality Criteria[b]
Sampling Dates	11/82	7/83	8/84	12/84	7/85	11/82	7/83	8/84	12/84	7/85	11/82	7/83	8/84	12/84	7/85	11/82	7/83	8/84	12/84	7/85	
dichloromethane	ND	LC	3.4	ND	ND	ND	LC	2.0	0.4	0.5	ND	LC	3.9	0.5	ND	ND	LC	4.2	ND	ND	
chloroform	ND	D	0.4	ND	ND	ND	D	0.3	ND	ND	ND	D	0.5	0.1	ND	ND	D	0.7	ND	ND	90[c]
1,1-dichloroethane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
1,2-dichloroethane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	
1,1,1-trichloroethane	NR	ND	ND	0.4	ND	NR	ND	ND	0.1	ND	NR	ND	ND	0.7	ND	NR	ND	ND	0.3	ND	19,400[d]
1,2-dichloroethene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.1	ND	
trichloroethene	ND	T	D	ND	ND	T	T	D	ND	ND	ND	T	D	ND	ND	ND	T	D	ND	ND	
tetrachloroethene	ND	T	ND	ND	ND	ND	T	ND	ND	ND	ND	T	ND	0.2	T	ND	T	ND	ND	ND	
benzene	2	D	0.2	2.3	2.1	9	D	0.2	4.7	1.0	5	ND	0.1	2.9	3.3	21.0	D	0.4	39.6	3.4	950[d]
toluene	4	15.5	0.6	15.9	1.3	42	6.1	0.4	2.0	0.6	11	ND	0.6	2.7	1.4	29.0	22.4	0.9	5.2	1.3	490[d]
xylenes	2	5.5	0.1	0.9	T	3	2.4	0.1	1.3	ND	3	3.8	0.2	1.7	0.7	28.0	3.1	0.1	1.7	T	490[d]
ethylbenzene	ND	T	0.02	0.2	ND	ND	T	0.02	0.5	ND	ND	ND	0.03	0.4	T	5.0	T	0.03	0.1	ND	850[d,e]
C_3-benzenes	NR	0.6	T	T	ND	NR	ND	T	T	ND	NR	ND	T	T	ND	NR	0.6	T	T	ND	
C_4-benzenes	NR	9.4	T	T	ND	NR	ND	T	ND	ND	NR	ND	T	ND	ND	NR	0.05	T	T	ND	
styrene	ND	LC	T	ND	T	5	LC	T	ND	ND	ND	LC	T	ND	ND	LC	LC	ND	0.2	ND	90[d]
1,4-dichlorobenzene	ND	1.1	0.4	ND	ND	ND	0.4	0.1	ND	ND	ND	0.4	0.4	0.8	T	ND	0.9	0.4	0.6	ND	
naphthalene	ND	ND	0.01	T	ND	ND	ND	ND	T	ND	ND	ND	0.002	T	0.4	ND	ND	0.02	T	ND	
acetone	20	NR	5.2	ND	2.6	ND	NR	2.9	ND	ND	ND	NR	6.8	ND	1.4	ND	NR	3.3	2.4	7.0	18,540[d]
benzaldehyde	NR	ND	ND	ND	1.2	NR	0.8	ND	ND	ND	NR	ND	ND	ND	T	NR	ND	T	ND	2.7	
diethyl ether	NR	NR	0.8	ND	ND	NR	NR	0.6	ND	ND	NR	NR	0.6	ND	ND	NR	NR	1.1	ND	ND	

Notes: Location of sampling sites shown in Figure 12.

[a] All samples collected by Tenax tubes and analyzed by Mann Testing Laboratories.
[b] As established by the Ontario Ministry of the Environment, Feb 1, 1986 (24 hour average exposure for ambient air).
[c] Ministry of the Environment guideline.
[d] Ministry of the Environment standard.
[e] One hour average, rather than 24 hour average.

All reported values below 1 ppb are semiquantitative; actual amounts present are unlikely to exceed the values reported and are less than 1 ppb.

T means Detected but not quantified; concentrations well below 1 ppb.
ND means the compound was searched for; if present, the amount is below the detection limit.
LC means Laboratory Contamination. Compound may or may not be present in sample.
NR means the presence or absence of the compound was not reported by the laboratory.

E. POLYCYCLIC AROMATIC HYDROCARBONS (PAHs) IN AMBIENT AIR

E1. METHODS

The standard method used for the sampling of PAHs in air is to pump a large volume of air (one to two thousand cubic metres) through a high volume (hi-vol) filter to trap particulates. It has been shown that the lower PAHs are not quantitatively collected by this method because of their significant volatility. A new protocol has recently been developed by the Air Resources Branch of the Ontario Ministry of the Environment and is currently being implemented.(23) Of the refinements being made, the most important is the addition of a sorbent tube to capture the 'break through' of PAHs from the hi-vol filter.

Since the equipment required for this new procedure was not available, it was decided to use the standard method and to restrict the analysis to the higher molecular weight PAHs, dibenzo(a,h)anthracene, benzo(a)pyrene and benzo(g,h,i)-perylene, which, because of their low vapour pressure, are more effectively removed by the hi-vol filter. This has the advantage that it permits a better comparison with previous measurements of PAHs in the Hamilton area. Furthermore, the higher molecular weight PAHs have been of greatest concern in relation to their carcinogenic activity.

Samples were collected at three sites: upwind (Site 15), downwind (Site 14) and at an off-landfill control site (Site 31). Sampling volume for each was 2000 m^3 collected over a twenty-four hour period. For purposes of quantification, standards (i.e., containing pure deuterated samples) of the three PAHs being analyzed were applied to the filters prior to air sampling. Following air sampling, the filters were extracted with dichloromethane, the extracts concentrated and injected into a GC-MS system for analysis.

E2. FINDINGS

The results of the air analysis for the three targeted PAHs at the three offsite locations are shown in Table 31.(24) Concentrations are given in nanograms per 1000 cubic metres (ng/1000m^3).* It is seen that there are no significant differences among the three sites, showing that insofar as the three representative PAHs are concerned, the landfill makes a negligible contribution to the PAH content of air in the vicinity of the site. The concentrations observed in this work cannot be directly compared to those previously found in the Hamilton

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* One ng per m^3 corresponds to about 0.1 parts per trillion, if the PAHs were in the gaseous form.

Table 31: Analysis of Ambient Air for Polycyclic Aromatic Hydrocarbons (PAHs)[a] (ng/1000m^3)

	Upwind (Site 15)	Downwind (Site 14)	Control (Site 31)
benzo(a)pyrene	56.9	58.0	56.5
dibenzo(a,h)anthracene	ND	ND	ND
benzo(g,h,i)perylene	81.8	81.8	73.8

Notes: Location of sampling sites shown in Figure 12.

[a] Air samples collected with a hi-vol filter (standard 20 cm by 25 cm glass fibre) and analyzed by quantitiative GC-MS for three target PAHs by Mann Testing Laboratories.

ND means the compound was searched for; if present, the amount is below the detection limit.

area because of the differences in sampling conditions and methods of analysis. Nevertheless, it is interesting to note that previous hi-vol samples collected in the downtown industrial area of Hamilton showed benzo(a)pyrene in concentrations ranging from 1,400 to 3,500 ng/1,000 m^3 and benzo(g,h,i)perylene in concentrations of 6,420 to 7,530 ng/1,000 m^3. (25)

F. ATMOSPHERIC DISPERSION OF LANDFILL GAS

The results of atmospheric testing in the neighbourhood of the landfill over a three-year period showed concentrations of contaminants at sampling sites downwind of the landfill, which were no higher, and frequently lower, than concentrations upwind of the landfill and at a control site. From this it would appear that the contribution of landfill-sourced pollutants to the overall contamination levels in the neighbourhood of the landfill is small compared to that from other sources. On the other hand, it should be noted that these analyses were limited both with respect to their frequency and the sampling site locations. It is possible that climatic conditions at the various times of sampling were particularly favourable to atmospheric dispersion and that the time-average concentrations at certain locations in the vicinity of the landfill might be significantly higher than background.

It is possible to gain some insight into this matter as a result of an atmospheric dispersion study at the site carried out by CJB Associates Inc.(26) This study was commissioned by the Committee in the hope that it might be possible to 'model' retrospectively the patterns of concentration in ambient air in the neighbourhood of the landfill during the most active period of its use for the disposal of industrial wastes, i.e., 1976 to 1980. This objective was not achieved, unfortunately, because of the inability to estimate within any meaningful range of values the probable levels of emission from the site during this period of active operation. Nevertheless, the atmospheric dispersion data provided by this study afford the means of calculating the contribution of current landfill emissions to the overall ambient air pollution levels in the vincinity of the site. In other words, it is possible to test the 'reasonableness' of the conclusions from the ambient air analyses that current atmospheric pollution in the neighbourhood of the landfill originates primarily from sources other than the landfill.

The atmospheric dispersion study was based on meteorological data obtained at the Mount Hope Airport, some 9 km from the site, for the period of 1976-80. Although this is a different period than that during which ambient air analyses were carried out, normal year-to-year variations in dispersion climatology have been shown not to produce significant variations in predicted concentrations of contaminants. Calculations were carried out using both annual and summer (June, July and August) climatic conditions. While a number of different potential sources of landfill emissions was examined in the study, the one which is most relevant to current emissions assumes that the whole of the landfill is the emission source.

The results expressed in terms of ground level concentrations ($\mu g/m^3$) resulting from an overall emission rate of one gram of a particular chemical per second (g/s) is shown in Figure 13 (on an annual basis) and in Figure 14 (for the summer period). Two conclusions can be drawn:

a) the highest exposures are to the immediate northeast of the site, and

b) beyond the first few hundred metres, exposures are relatively uniform with respect to wind direction, except in the northwest direction where they are relatively lower.

These results relate only to the relative levels of ambient air contamination in the vicinity of the site; that is, they show the average concentration of contaminants at any point at a emission rate of one gram per second of that contaminant from the landfill. To determine absolute levels it is necessary to know, as well, the actual rate of emission. As stated earlier in this Section, this proved impossible to estimate retrospectively for the period of active landfill operation. A reasonable approximation, however, can be made for current emissions using the observed concentrations of contaminants in the vent gas and an estimate of the total rate of emission of this gas at the site.

Conestoga-Rovers and Associates Limited (CRA), the Committee's consultants on the feasibility of collecting and burning the landfill gas, estimated that the total gas production rate at the landfill to be in the range of 27 to 81 million cubic metres per year (see page 170). This is high compared to that observed by CRA elsewhere. Nonetheless, the higher figure of 81 million cubic metres is used in calculating the emission rates of individual contaminants, since the purpose of the calculation is to estimate the maximum probable contribution of the landfill to the concentration of contaminants in the neighbourhood of the site. Similarly, the highest concentrations observed in the vent gases (see Table 24) were used in these calculations.

The estimated emission rates were used to calculate a range of concentrations for landfill-sourced contaminants using the dispersion model relationships shown graphically in Figure 13, namely an emission of one g/s results in concentrations in nearby residential areas of 0.5 $\mu g/m^3$ to 2.0 $\mu g/m^3$. The results are shown in Table 32.

It is seen that the calculated concentrations of landfill-sourced contaminants are small compared to the concentrations observed in the air survey analyses (Table 30). This supports the conclusion reached earlier that the landfill is not the primary source of the major contaminants found in residential areas in proximity to the landfill.

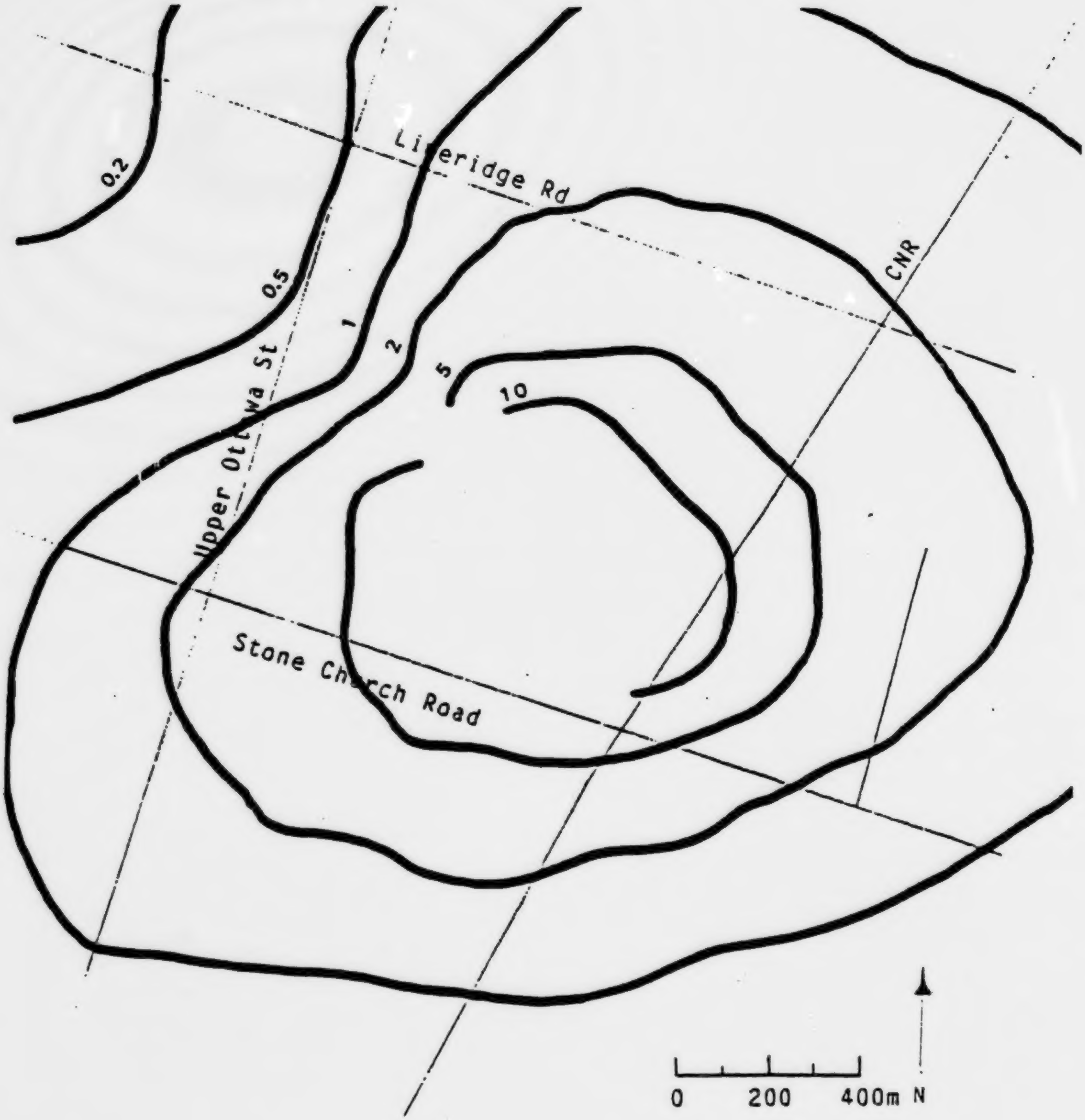
0.2
0.5
1
2
5
10
Liveridge Rd
CNR
Upper Ottawa St
Stone Church Road
0
200
400m
N

FIGURE 13: Annual Ground Level Concentrations (µg/m3) due to Unit Emission Rate (1 g/s) from Source e) - Total Landfill Area

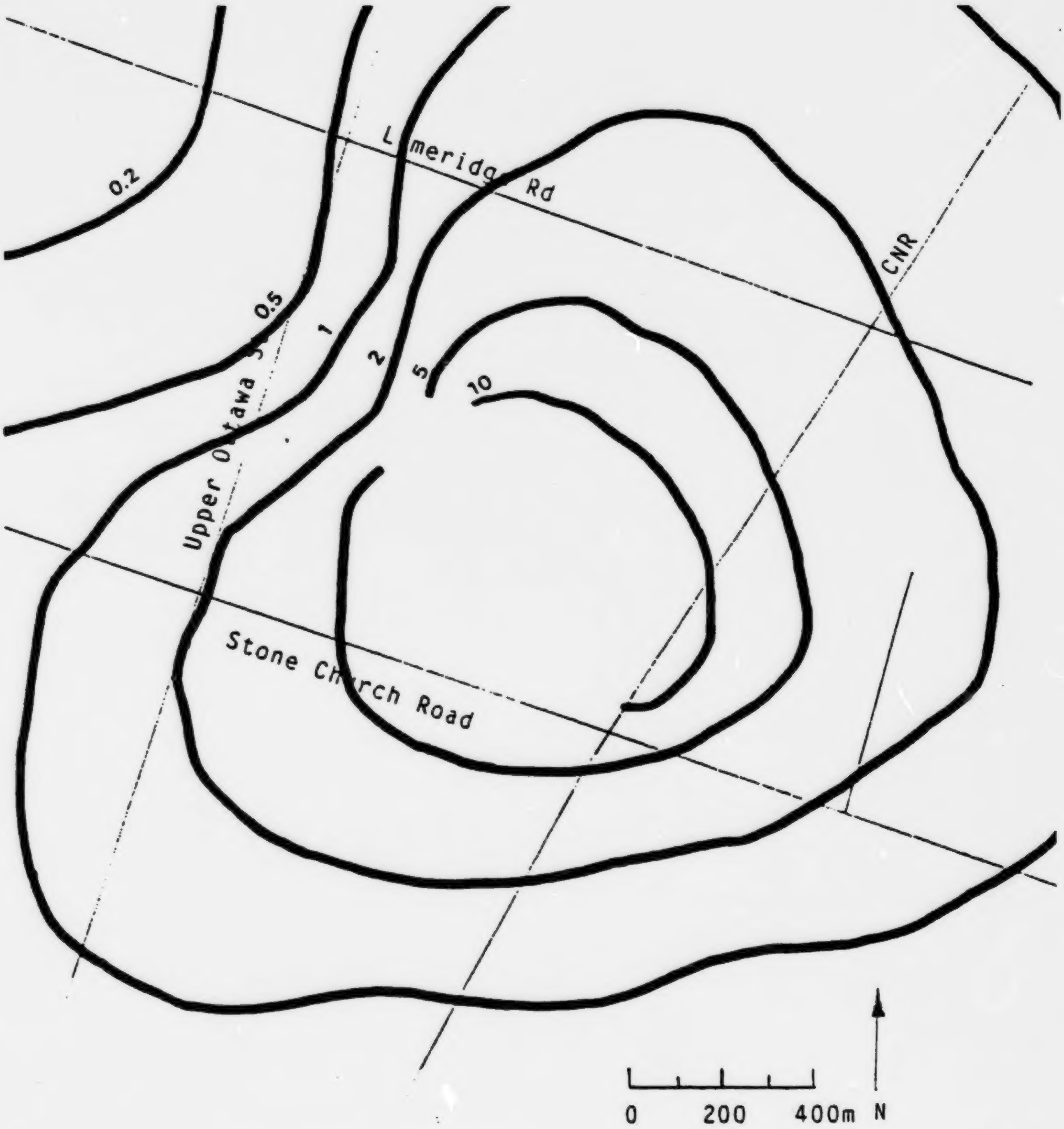
0.2
0.5
1
2
5
10
Limeridge Rd
Upper Ottawa St
Stone Church Road
CNR
0 200 400m
N

FIGURE 14: Summer Ground Level Concentrations (µg/m3) due to Unit Emission Rate (1 g/s) from Source e) - Total Landfill Area

Table 32: Estimated Emission Rates and Atmospheric Dispersion of Major Landfill-Sourced Contaminants

	Estimated Emission Rates		Calculated Concentrations of Landfill-Sourced Contaminants in Nearby Residential Areas		Average Observed Concentrations in Residential Areas	Air Quality Criteria [a]
	g/s	ml/s	µg/m^3	ppb	ppb	ppb
benzene	0.04	12.9	0.02 - 0.08	0.006 - 0.025	2.2	950
toluene	2.1	520	1.0 - 4.0	0.25 - 1.0	7.0	490
xylenes	0.7	160	0.4 - 1.5	0.08 - 0.3	1.6	490
1,1,1-trichloroethane	0.1	17.7	0.05 - 0.2	0.01 - 0.04	(1)[b]	19,400
tetrachloroethene	0.01	1.0	0.004 - 0.02	0.0005 - 0.002	(1)[b]	

[a] Established as standards by the Ontario Ministry of the Environment, Feb. 1, 1986 (24 hour average exposure for ambient air).

[b] Detected in a few air samples only.

G. MUTAGENICITY ASSAYS

G1. INTRODUCTION

The mutagenicity work on air involved separate Ames testing programs for landfill gas and for air particulates.

There is no established methodology for Ames testing of vapour phase samples such as landfill gas. This study began with experiments by Mutatech to establish which of three possible methods would be most effective in the detection and quantification of mutagenic activity in landfill gas.

The second Ames testing program dealt with air particulates. It was designed to compare the levels of mutagens at the landfill with levels elsewhere in the city.(27) During the last decade, research on mutagenicity of air has found that many organic contaminants are found on the surface of air particulates and that particulates in the size range from 10 micrometres downward penetrate within the lungs and lodge there.

G2. METHODS

G2.1 Landfill Gas

Mutatech developed three methods of exposing Ames tester 'strains' to the landfill gas: a 'closed chamber' ('desiccator') method, a 'bag' method and a 'bubbling' method in which the gas to be tested was bubbled through a suspension of test bacteria. The initial field work employed the three methods and four Ames strains (TA98, TA100, TA1535 and TA1537) but the laboratory validation and field work showed that the 'desiccator' method was the most sensitive and that TA98 and TA100 were the most sensitive test bacteria. The methods of analysis used closely resembled those described by Ames et al. in 1975 and Salamone et al. in 1979.

G2.2 Air Particulates

Air particulates were collected over a 24 hour period using hi-vol samplers. The sample was extracted from the filter in a soxhlet extractor with methanol. The limited quantity of air particulates collected necessitated a change of protocol so that only the three most sensitive strains of bacteria (TA98, TA100 and TA1537) were used rather that the five strains used in the assays of leachate and surface water. The Ames assay procedures used for air particulates used closely resembled the methods described by Ames et al. in 1975 and Salamone et al. in 1979.

G3. FINDINGS

G3.1 Landfill Gas

Field experiments were conducted using the 'desiccator' method to collect gas from a gooseneck vent on the landfill (Site 8). While the exposed plates showed some increase over controls in the number of revertants, in no case was there a dose-response relationship. Further, these exposed plates failed to show the two-fold increase in revertants over background generally expected before a positive result can be claimed. It is concluded that mutagenic activity has not been positively demonstrated although low levels could be present.(28)

G3.2 Air Particulates

Samples of air particulate matter for the Ames test were collected from ten locations shown in Figure 11: near Sites 3, 11, 12, and 13 on the landfill, the Bell Canada building (on the south side of Stone Church Road opposite the landfill), the fire training facility (Site 15) to the immediate south and west of the landfill, Blessed Kateri School (Site 20), and three control sites (Stoney Creek, downtown Hamilton, and the west mountain).

Data on the mutagenicity of urban air in various parts of the world generally show a range from less than one to ten reverants per cubic metre and all samples tested by Mutatech fell within this low range.(29) A maximum of 2.9 revertants per cubic metre was found at the southeast side of the landfill (Site 1) using TA98, which proved to be the most sensitive strain. Mutagenicity levels comparable to, or greater than, Upper Ottawa Street landfill samples were found at the control sites.

H. COLLECTION AND FLARING OF LANDFILL GAS

H1. INTRODUCTION

Concurrent with the program of landfill gas and air analyses, the Committee commissioned a study of the feasibility of collecting and flaring the landfill gas. This study was carried out in the winter of 1982-83 by Conestoga-Rovers and Associates (CRA) who retained Mann Testing Laboratories (MTL) for organic chemical analyses.(30) The results of the gas analyses performed in this study supplement those reported in Section B of this chapter.

H2. FEASIBILITY OF COLLECTING AND FLARING THE LANDFILL GAS

In order to evaluate the feasibility of collecting and flaring the landfill gas, it was necessary to measure the gas recovery rate and to determine whether or not the composition of the gas is such as to maintain continuous high temperature combustion. To this end, the consultants installed a 9.8 metre deep test well (Site 1) on the Stone Church Road side of the site and five gas probe nests, ranging in depth from 3.0 to 7.8 metres and spaced at distances of 9.1 to 47.5 metres from the well. An existing gooseneck vent and a single probe beside the test well served as additional gas probes. The purpose of the gas probes was to determine the distance over which gas could be drawn by pumping at the well. The location of the gas well and probes is shown in Figure 12.

It was found from pressure measurements at the gas probes that at a pumping rate of one cubic metre per minute over a 31 hour period, gas was being drawn from the most distant probe and that the zone of negative pressure, corresponding to complete gas control, extended approximately 15 metres from the well. Assuming that, by the end of the pumping test, equilibrium had been achieved between the rate of gas production and the rate of gas recovery, the consultants estimated a gas recovery rate of between 0.02 and 0.06 cubic metres per kilogram of refuse per year (0.3 to 0.9 cubic feet per pound per year). This rate is high compared to typical gas recovery rates from actual operating gas recovery facilities which range from 0.003 to 0.01 cubic metres per kilogram per year (0.05 to 0.15 cubic feet per pound per year). Also, it is high compared to the results of similar short term pumping tests conducted by CRA at other sites in Southern Ontario, where rates of 0.01 to 0.03 cubic metres per kilogram per year (0.17 to 0.40 cubic feet per pound per year) were observed. This result is consistent with the fact that conditions for gas production at the site appeared to be optimal, namely, a high moisture content within the refuse and elevated temperatures in the order of 30°C to 50°C.

It has been estimated by the Regional Municipality of Hamilton-Wentworth that approximately 2.3 million cubic metres of refuse are in place at the site. Assuming an average density of 590 kilograms per cubic metre (1000 pounds per cubic yard), the total amount of refuse in the site is approximately 1.35 million metric tonnes. From this and the calculated gas recovery rate of 0.02 to 0.06 cubic metres per kilogram of refuse per year, it was estimated that the total annual rate of gas production at the landfill is in the range of 27 to 81 million cubic metres per year. It should be noted that this estimate is based on the assumption that conditions at the test well location are characteristic of the total site.

Samples of landfill gas collected in gas bags and analyzed by CRA using a Fisher Model 1200 Gas Partitioner were found to contain from 55 to 59 per cent methane. Other major constituents were carbon dioxide, 29 per cent, and nitrogen, 2 to 8 per cent. The gas was clearly suitable for combustion.

A flaring apparatus was designed in which measured quantities of landfill gas and air were premixed prior to combustion. It was found that a ratio of landfill gas to air of 1:10 was most suitable for efficient combustion. The maximum measured temperature in the combustion chamber using this ratio was 950° C and the concentration of methane in the gas after it was flared was 0.2 per cent.

H3. COMBUSTION EFFICIENCY FOR TRACE ORGANICS

H3.1 Methods

Two sampling methods, one using air bags and the other Tenax sorbent tubes, were employed in the analyses of pre- and post-flare gas for trace organic constituents. The air bag samples were analyzed by gas chromatography using an electron-capture detector (ECD) which selectively detects halogenated compounds. The Tenax tube samples were thermally desorbed and analyzed by conventional gas chromatography-mass spectrometry (GC-MS).

H3.2 Findings

The results of the pre- and post-flare gas analyses are shown in Table 33.(31) Since standards were not used in the GC-MS analysis reported in this table, the concentrations shown are not accurate in an absolute sense. They cannot be compared, therefore, with the results reported in Tables 22 to 26. Their purpose is to show the relative concentrations of constituents in pre- and post-flare gas and, therefore, the effectiveness of the flaring.

It is seen that 1,1,1-trichloroethane, which was found at a concentration of 2.2 ppm in the combustion chamber before flaring, was reduced to a concentration of 0.05 ppm after flaring. This establishes that 98 per cent of this chlorinated organic was destroyed. The two other chlorinated compounds, dichloroethene and tetrachloroethene, were found in the pre-flared gas but were not detected after flaring.

Benzene, naphthalene and benzofuran appear to have lower combustion efficiencies than do the other organics. The fact that the concentration of naphthlene is lower in the post- than in the pre-flared gas (0.4 ppm compared to 1 ppm) might be taken as an indication that the concentrations of PAHs in general are reduced by the flaring process. This, however, requires further study.

There is no evidence that chlorinated aromatics (e.g., chlorinated benzenes, phenols or biphenyls) were being formed during landfill gas combustion. These compounds would have been detected had they been present in concentrations greater than one ppb. They are the precursors of the highly toxic polychlorinated dibenzo(p)dioxins (i.e., dioxins) and dibenzofurans. The lack of chlorinated organics suggests that the formation of these compounds during the flaring of landfill gas is negligible.

Table 33: **Concentrations of Trace Organics in Pre- and Post-Flaring Landfill Gas**
parts per million

	Pre-Flare Landfill Gas (Diluted 10:1 with Air)	Post-Flare Gas
ECD[a]		
1,1,1-trichloroethane	2.2	0.05
dichloroethene	BRQL	ND
tetrachlorothene	BRQL	ND

(ppm but values are relative only to the concentrations of toluene)

	Pre-Flare Landfill Gas (Diluted 10:1 with Air)	Post-Flare Gas
GC-MS[b]		
furan	30	1.0
sulphur dioxide	2.0	5.0
benzene	47	9.0
toluene	102	4.0
C_2-benzenes	88	0.4
C_3-benzenes	43	0.1
C_4-benzenes	6.0	ND
dihydroindene	10	0.2
indene	1.6	0.1
dichlorobenzene	1.9	ND
benzofuran	0.4	0.2
benzaldehyde	ND	0.4
C_1-benzaldehydes	ND	0.2
naphthalene	1.0	0.4

Notes:

[a] Samples collected from Site 1 (See Figure 12) in air bags and analyzed by Mann Testing Laboratories using gas chromatography with electron-capture detection.

[b] Samples collected from Site 1 by Tenax tubes and analyzed by Mann Testing Laboratories using gas chromatography-mass spectrometry (GC-MS). Concentrations are relative to the concentration of toluene in the sample. Amounts are approximate only and cannot be compared to those in other tables.

BRQL means the compound was detected but below Reliable Quantification Limit.
ND means the compound was searched for; if present, the amount is below the detection limit.

Nitromethane was the only compound that had not been detected previously in the landfill gas but was found in the post-flaring gas, at a concentration of roughly 5 ppm. This compound is not toxic except in relatively high concentrations. Small amounts of benzaldehyde and C_1-benzaldehyde would appear to be formed during combustion as well, probably as a result of the oxidation of toluene and xylene. These compounds also are of low toxicity.

It was observed during the flaring tests that the foul odor of the landfill gas was eliminated. This was because of the oxidation of organic sulfur compounds to sulfur dioxide.

H4. EFFECT OF CONTINUOUS PUMPING

One concern relating to the collection and flaring of landfill gas is the possibility that active pumping might bring to the surface higher concentrations of toxic compounds than would be emitted passively through the landfill cover.

Experiments were performed in which the concentrations of four compounds, toluene, xylene, 1,1,1-trichloroethane and tetrachloroethene, were measured for landfill gas emitted passively from gooseneck vents, shallow gas probes and the deep test well (Site 1) and for the pumped gas from Site 1.(32) Whereas the concentrations of the aromatic hydrocarbons were essentially the same in all samples, marked differences were observed in the case of 1,1,1-trichloroethane. This compound was being emitted passively from the shallow gas probes in concentrations of approximately one ppm and from the deep test well in a concentration of five to seven ppm. Pumping at this deep test well, however, brought to the surface landfill gas containing approximately 12 ppm of this chlorinated hydrocarbon. Furthermore, this high concentration was maintained even after 24 hours pumping. A similar, although much less marked, trend was observed in the case of tetrachloroethene.

This substantial increase in concentration of chlorinated hydrocarbons due to pumping must be considered within the context that flaring was shown to destroy about 98 per cent of 1,1,1-trichloroethane. Also, it is possible that after long continuous pumping the concentrations of the chlorinated hydrocarbons would decrease to the levels found in the passively venting gas.

H5. CONCLUSIONS

The gas collection studies carried out by Conestoga-Rovers and Associates have shown that optimum conditions exist for gas production and combustion: methane concentrations are in the high range of 55 to 59 per cent by volume; temperatures within the landfill are in the upper end of the optimum range for methane production of 30°C to 50°C; combustion efficiency for most organics is greater than 90 per cent and for the chlorinated organics in excess of 95 per cent; and toxic compounds do not appear to be formed in significant quantities during combustion. Furthermore, a very large volume of gas is being produced, in the order of 50 million cubic metres per year, and this gas contains significant concentrations of aromatic and chlorinated hydrocarbons.

On the basis of these findings, the consultants concluded that, if a landfill gas control system were to be constructed at the site, the most technically feasible system is one involving active (as opposed to passive) landfill gas collection and flaring. It was recommended that the installation of such a system should be carried out in three stages with the results of each stage being used to refine the design and confirm the necessity of the following stages.

In the first stage, a continuous pumping and flaring test would be carried out for at least a month on three test-wells on the Stone Church Road side of the site. This test would provide detailed design data for the gas control system and verify the assumptions made in the feasibility study.

The second stage would involve construction of a permanent installation along the Stone Church Road side of the site. Based on CRA's preliminary design concept, which might be modified in the light of findings in stage one, this installation would consist of a network of wells (approximately three metres deep and spaced 30 metres apart), connected through lateral pipes leading to a pumping system and a flare plant. The consultants' estimated cost for this installation was $600,000, with an additional annual operation and maintenance cost of $50,000.

The third stage would involve constructing a system, similar to the one installed in the second stage, on the Red Hill Creek side of the landfill. Modifications might be required because of the extremely steep slopes on the north side of the site. This installation was estimated to require a capital outlay of $500,000 with some additional operation and maintenance costs.

The consultants also recommended that the potential for energy utilization from the landfill flaring system be reviewed for feasibility.

A decision on whether or not to install a gas collection and flaring system at the landfill can only be made in the context of the overall findings of the Study Committee's investigation. This matter is addressed in Chapter 13, entitled Conclusions and Recommendations.

References

1. Paul J. Lioy and Joan M. Daisey, "The New Jersey Project on Airborne Toxic Elements and Organic Substancs (ATEOS): A Summary of the 1981 Summer and 1982 Winter Studies," Journal of the Air Pollution Control Association 33:7 (July 1983): 649-657.

2. Ronald Harkov, Barbara Kebbekus, Joseph W. Bozzelli and Paul J. Lioy, "Measurement of Selected Volatile Organic Compounds at Three Locations in New Jersey During the Summer Season," Journal of the Air Pollution Control Association 33:12 (December 1983): 1177-1183

3. J.W. Bozzelli and B.B. Kebbekus, "Selective Gas Chromatographic Detection of Vapor-Phase Organics in Ambient Air, "Sampling and Analysis of Toxic Organics in the Atmosphere. ASTM STP 721. American Society for Testing and Materials, 1980, pp. 70-79.

4. Edo D. Pellizzari, "Analysis for Organic Vapor Emissions near Industrial and Chemical Waste Disposal Sites," Environmental Science and Technology 16 (1981): 781-785.

5. Ontario, Ministry of the Environment, correspondence of Laboratory Services Branch (Organic Trace Contaminants Section) with Stoney Creek Regional Office, February 24, 1981, April 30, 1981 and September 29, 1981.

6. Ontario Ministry of the Environment (Technical Support Section of Hamilton District Office), correspondence with Mr. Ron Bridgland, January 4, 1982.

7. Conestoga-Rovers and Associates Limited. Feasibility Study of Landfill Gas Control at the Upper Ottawa Street Landfill. March 1983.

8. Kenneth J. Krost, Edo D. Pellizzari, Stephen G. Walburn and Sarah A. Hubbard, "Collection and Analysis of Hazardous Organic Emmissions," Analytical Chemistry, 54:4 (April 1982): 810-817.

9. Mann Testing Laboratories Ltd. Analysis of Outgassing from Test Probes, Bore Hole and Test Well, November 1, 1985.

10. Ibid.

11. Ibid. and
Mann Testing Laboratories: Quantification of Selected Volatile Organics at the Upper Ottawa Street Landfill Site, February 28, 1983.

12. Edo D. Pellizzari, "Analysis for Organic Vapor Emissions near Industrial and Chemical Waste Disposal Sites," Environmental Science and Technology 16 (1982): 781-785

13. Mann Testing Laboratories Ltd., Ambient Air Analysis of Landfill and Peripheral Sites, December 31, 1984.

Mann Testing Laboratories Ltd., Ambient Air Analysis of Landfill and Peripheral Sites, January 21, 1985.

14. Mann Testing Laboratories Ltd., Sampling and Analysis of Polynuclear Aromatic Hydrocarbons, December 10, 1985.

15. Sciex, Report on Air Quality Surveys at the Upper Ottawa Street Landfill Site, February, 1982.

16. Sciex, Final Report on Air Quality Surveys at the Upper Ottawa Street Landfill Site, January, 1983.

17. Sciex, Identification of Volatile Organic Compounds at the Upper Ottawa Street Landfill in Hamilton, Ontario, prepared for the Ontario Ministry of the Environment: Air Resources Branch, Air Research and Special Programs Section, Summer 1981.

18. Sciex, Report on Air Quality Surveys in the Upper Ottawa Street Landfill Site, February 1982.

19. Mann Testing Laboratories Ltd., Report on Ambient Air Analysis of Landfill and Peripheral Sites, August 21, 1985.

20. Ibid.

21. Mann Testing Laboratories Ltd., Reports on Ambient Air Analysis of Landfill and Peripheral Sites: December 1982; November 15, 1983; October 18, 1984; December 31, 1984; January 21, 1985 and August 21, 1985.

22. Ronald Harkov, Barbara Kebbekus, Joseph W. Bozzelli and Paul J. Lioy, "Measurement of Selected Volatile Organic Compounds at Three Locations in New Jersey During the Summer Season", Journal of the Air Pollution Control Association 33:12 (December 1983): 1177-1183

23. Concord Scientific Corporation, Evaluation of Alternatives to Hi Vol Sampling for Polynuclear Aromatic Hydrocarbons, prepared for the Ontario Ministry of the Environment, March 1984.

24. Mann Testing Laboratories Ltd., Analysis of Three Polynuclear Aromatic Hydrocarbons From High-Volume Filters, December 19, 1985.

25. M. Katz, T. Sakuma and A. Ho, "Chromatographic and Spectral Analysis of Polynuclear Aromatic Hydrocarbons -- Quantitative Distribution in Air of Ontario Cities," Environmental Science and Technology 12 (1978): 909-915.

26. CJB Associates Inc, Atmospheric Dispersion Study of the Upper Ottawa Street Landfill Site, February 1986.

27. Mutatech Inc., Report on the Analysis of Air Particulates and Leachates from the Upper Ottawa Street Landfill for Mutagenicity in the Ames Tests, November 1982.

28. Mutatech Inc., Report on Laboratory Validation of Field Experiments Carried Out at the Upper Ottawa Street Landfill Site, August 1982

Mutatech Inc., Report: Ames Tests on Gases Emanating From Vents on the Upper Ottawa Street Landfill, September 1983.

29. B. Commoner, P. Madyastha, A. Brownsdon and A.J. Vitayathil, "Environmental Mutagens in Urban Air Particulates," Journal of Toxicology and Environmental Health 4 (1978): 59-77.

M. Moller and I. Alshein, "Mutagenicity and PAH - Analysis of Airborne Particulate Matter," Atmospheric Environment 14 (1980): 83-88.

C.Y. Wang, M. Lee, C.M. King and P. Warner, "Evidence for Nitroaromatics as Direct-Acting Mutagens of Airborne Particulates," Chemosphere 9 (1980): 83-88.

30. Conestoga-Rovers & Associates Limited, Feasibility Study of Landfill Gas Control at the Upper Ottawa Street Landfill, March, 1983.

31. Mann Testing Laboratories Ltd., Chemical Analysis of Pre- and Post-Flare Gases, January, 1983.

32. Mann Testing Laboratories Ltd., Quantification of Selected Volatile Organics at the Upper Ottawa Street Landfill Site, February, 1983.

CHAPTER 9

IMPLICATIONS FOR HUMAN HEALTH OF EXPOSURE TO CHEMICALS FROM THE LANDFILL

Table of Contents

Page

A. INTRODUCTION 180

B. EXPOSURE TO CHEMICALS FROM THE LANDFILL 180

B1. INTRODUCTION 180

B2. EXPOSURE BY WAY OF SURFACE WATER 180

B3. EXPOSURE BY WAY OF AIR 182

C. POTENTIAL EFFECTS ON HUMAN HEALTH 182

C1. INTRODUCTION 182

C2. ASSESSMENT OF CURRENT EXPOSURE TO SPECIFIC COMPOUNDS 183

C3. RISK ASSESSMENT OF PAST EXPOSURE 187

D. CONCLUSIONS 188

D1. LEACHATE

D2. SURFACE WATER 188

D3. AIR 188

Tables Page

34 Known or Suspected Carcinogens Detected in Surface Water, Leachate or Sediment at Concentrations Above Drinking Water Criteria 184

References 189

A. INTRODUCTION

The presence of a chemical waste disposal site, which contains a number of potentially hazardous substances and shows some signs of leaking, in a populated area is undesirable at the very least from an aesthetic point of view. Whether the chemicals in the landfill present a risk to the health of the public, however, depends on two major factors: 1) the inherent toxic properties of the chemicals present, and 2) the magnitude and route of human exposure to the chemicals. For example, if none of the chemicals were capable of causing cancer, there would obviously be no risk of cancer due to the presence of the landfill. Conversely, even if chemicals that could cause cancer were present, these would present a risk only if people came into contact with them in amounts sufficient for their cancer-causing potential to be expressed.

In the analysis which follows, the potential for human exposure to chemicals from the landfill is discussed first. This is followed by a discussion of the toxic properties of the chemicals from the landfill identified in the landfill leachate, in the sediments and surface waters, and in landfill gas and the air.

B. EXPOSURE TO CHEMICALS FROM THE LANDFILL

B1. INTRODUCTION

Exposure to a chemical deposited in a landfill can occur in several ways. The chemical may leach into surface water (rivers and streams) or groundwater and people may be exposed by drinking the water or by coming into contact with it. In the case of the Upper Ottawa Street landfill, groundwater is not used to supply drinking water, so this is not an immediate public health concern. If the chemical is volatile, or if it is on the surface of fine dust particles, it may escape into the air and people may be exposed by inhalation. A fourth possibility relates to direct contact with the contents of the landfill. Since the landfill is mostly fenced and covered, however, direct contact is limited.

The present discussion, therefore, will address the two most likely routes of exposure: surface water and air.

B2. EXPOSURE BY WAY OF SURFACE WATER

As discussed in Chapter 5, leachate springs have been observed on the sides of the landfill and the nearby Red Hill Creek (into which some of these springs drain) has shown some contamination. Fortunately, the creek does not supply drinking water in the area.

Another pathway of potential exposure would be the consumption of fish caught in Red Hill Creek, or larger streams or rivers fed by Red Hill Creek.

This is of concern because some chemicals are taken up and concentrated by fish and other aquatic organisms. In some cases, the concentrations in the fish can be hundreds or thousands of times higher than in the water in which the fish live. It is understood, however, that little fishing occurs in affected streams or rivers.

A more probable means of exposure to these chemicals is children playing in, or beside, the creek, or on the sides of the landfill running down to the creek. This could result in contact with water and sediment from the creek, and possibly leachate from leachate springs on the side of the landfill (like those at Sites 9, 11, 12, 17 and 18 in Figure 6). Thus, one might imagine children paddling, or even swimming, in the creek and getting water and sediment on their skin, or scrambling up the side of the bank towards the landfill and coming into contact with a leachate spring. This would result in dermal (skin) exposure to the chemicals in these media (water, sediment and leachate). This route of exposure is likely to be limited and to occur mostly during the summer.

Two other routes of exposure from surface water have also been identified. The first is the Albion Falls Conservation Park, through which Red Hill Creek runs downstream of the landfill. Individuals coming into contact with water from the creek may be exposed to chemicals from the landfill. Again, children playing beside, or wading in the creek are the most likely ones to be exposed. Adults hiking in the park might also receive some exposure if they were to use creek water for food preparation or washing, though most people would be unlikely to use creek water in an urban area, even in a park, for this purpose. In any event, the fact that concentrations of known contaminants in the creek water at Albion Falls are not substantially higher than upstream of the landfill, indicates that chemicals leaching from the landfill contribute little to any exposure that might occur currently at Albion Falls. Should larger amounts of more toxic chemicals escape from the landfill in the future, of course, this potential pathway of exposure might assume greater importance.

The other potential pathway of exposure is from landfill leachate, specifically that from the leachate collection manhole (see Site 32 in Figure 6) which is discharging into the sanitary sewer and eventually reaches the city sewage treatment plant where some exposure to workers may occur. The amount discharged from the leachate collection manhole is estimated to be about 1,500 to 3,800 litres per day. This is diluted in the sewage (estimated at 227 to 379 million litres per day) that reaches the treatment plant. Because of this dilution, and because the chemicals identified in the leachate are typical of those which enter industrial sewage in low concentrations from other sources, the contribution of the landfill to total exposure of sewage plant workers is likely to be minimal. Also, sewage plant workers would no doubt be aware, at least in general terms, of the need to minimize contact with sewage. Thus, although some direct skin contact and possibly some exposure to vapours or aerosols may occur during the sewage treatment process, the degree of exposure is likely small, and chemicals from the landfill probably contribute little to the total exposure to chemicals in the sewage.

B3. EXPOSURE BY WAY OF AIR

Exposure resulting from the leaching of chemicals from the landfill into surface water is likely to involve only a relatively small number of individuals. Chemicals emitted into the air, however, could reach a much larger number of people. Fortunately, as discussed in Chapter 8, the contribution of the landfill to the levels of chemicals in the air in the vicinity of the landfill is small.

Although chemicals are being released from the landfill into the air, as shown by the measurements of landfill gases and vapours coming from the vents in the landfill (Tables 23 and 24), their concentrations are greatly reduced by dilution, even within a few metres from the vents (Table 25). In addition, many of the same chemicals identified in the landfill gas are common pollutants of urban air, and are present in the neighbourhood surveys from non-landfill sources (Tables 28, 29 and 30).(1)

Not only are chemicals diluted to near background levels by the time they reach residential areas, but the amounts of various chemicals released from the landfill apparently differ from day to day (Table 29). Although in principle, people living or working downwind of the landfill may receive some exposure to chemicals from the landfill, the magnitude of this exposure attributable to the landfill cannot be reliably estimated on the basis of the available data. For most of the chemicals detected, however, exposure is apparently not appreciably greater than that arising from background levels observed elsewhere in Hamilton or in other urban areas.

C. POTENTIAL EFFECTS ON HUMAN HEALTH

C1. INTRODUCTION

Once the chemical analyses of leachate, surface and groundwaters, and landfill gas and air were completed, the Committee commissioned consultants at Environ Corporation to assess the toxicological significance of the chemical findings in relation to the possible routes of exposure for people working and living near the landfill. In making this assessment, the consultants have used various techniques that involve the use of quantitative expressions of risk and comparisons with other types of risks in order to illustrate the degree or severity of the risk.

In evaluating potential effects on human health, a distinction is drawn between chemicals capable of causing cancer (carcinogens), and chemicals without this property (noncarcinogens). The distinction is important because whereas noncarcinogens are believed to display thresholds (i.e., levels of exposure below which no effect is produced) carcinogens are generally considered not to have thresholds. With carcinogens, the risk (i.e., the probability) of getting cancer gets smaller as the exposure gets smaller, but only reaches zero when exposure is zero.

Having said this, it is important to note that as exposure gets smaller, there comes a point at which the risk is much to small to measure. Regulatory agencies in Canada, the U.S., and other countries acknowledge this situation and, for many types of pollutants, set maximum acceptable exposure levels on the basis of an 'acceptable' level of risk (generally set at one excess case of cancer in a lifetime among 100,000 to 1,000,000 exposed people).

For noncarcinogens, safe exposure levels are those that are well below the estimated threshold for the toxic effects of the substance. Such thresholds are usually higher than the maximum acceptable exposure levels for carcinogens.

As a result, when there is exposure to a mixture of carcinogens and noncarcinogens, the possibility of a risk of cancer is generally of more concern, except in the case of the noncarcinogens that are very toxic and/or present in much higher concentrations than the carcinogens.

In the present situation, the noncarcinogens are, with few exceptions, present at low levels in air, water, leachate and sediment, and none is sufficiently toxic to present a serious hazard at these concentrations under the conditions of limited exposure likely to prevail at or near the Upper Ottawa Street landfill.

C2. ASSESSMENT OF CURRENT EXPOSURE TO SPECIFIC COMPOUNDS

In order to examine whether or not the carcinogens found in the leachate and gas emanating from the landfill or in the surrounding air, sediments and surface waters pose a significant risk, the Committee commissioned Environ Corporation to do a separate assessment of the hazard of each of the individual identified carcinogenic compounds or groups of compounds. Details for the relevant compounds are given in the text below and summarized in Table 34.

Benzene is known to cause leukemia in humans exposed to high concentrations by inhalation and a variety of types of cancer in animals exposed orally.(2) The concentrations found in leachate at the Upper Ottawa Street landfill are quite low (up to 9.1 ppb). By comparison, unleaded gasoline may contain about two per cent benzene, a concentration more than 2,000,000 times higher. Also, the concentration of benzene in the air downwind of the landfill is comparable to those at upwind locations and distant control sites; and it is substantially lower than concentrations found in the air at gasoline stations.(3)

Dichloromethane is a widely used solvent for which clear evidence of carcinogenicity has only recently been obtained.(4,5) Samples of water and leachate analyzed from seven of the leachate sites and two surface water sites show this chemical to be at levels below the criteria set for drinking water at all but one site (Site 32, the leachate collection manhole on the south side of the landfill). At Site 32, however, concentrations of 21,800 and 11,700 ppb were detected in October and December, 1984 respectively. For the more accessible sites, however, the concentrations are low (less than 20 ppb).

Although samples from Site 32 represent the material discharged to the sanitary sewer, very substantial dilution (about 100,000-fold) would occur before this material reached the sewage treatment plant, which means that exposure of the workers at the plant would be very low.

TABLE 34 : Known or Suspected Carcinogens Detected in Surface Water, Leachate or Sediment at Concentrations Above Drinking Water Criteria *

Chemical	Status	Maximum Concentration Detected
benzene	Known human and animal carcinogen	9.1 ppb in leachate
dichloromethane	Animal carcinogen	21,800 ppb in leachate at one sample site; others much lower
bis(2-ethylhexyl)-phthalate (DEHP)	Carcinogenic in mice and rats at high dose levels	360 ppb in leachate
aniline	Animal carcinogen	72.8 ppb in leachate
1,4-Dioxane	Animal carcinogen	18,663 ppb in leachate
PAHs	Some members of class are human and animal carcinogens	Less than 4 ppm total carcinogenic PAHs in sediment downstream of landfill
PCBs	Animal carcinogen	900 ppm in sediment

* See Tables 7, 14 and 15.

Some dichloromethane is also released into the air from the landfill (Table 23) but the concentration in the air downwind of the landfill is sufficiently diluted so that it is no higher than in upwind or other locations in Hamilton. Based on standard risk assessment procedures used by the U.S. EPA, however, the concentration of dichloromethane in air would need to be kept below about 0.1 ppb on average over a 70-year lifetime to ensure that lifetime risk is below one in 1,000,000. Thus, although the releases of dichloromethane from the landfill do not appear to add substantially to the background levels, these background levels themselves may be of some concern.

Bis(2-ethylhexyl)phthalate (DEHP) is widely used as a plasticizer to make vinyl plastics (PVC) soft and flexible. It is used in many household items, such as garbage bags, shower curtains, plastic footwear, artificial leather, children's toys, and swimming pool liners. The most flexible types of PVC may contain up to 40 per cent of this chemical. High concentrations in the diet were recently shown to be carcinogenic in mice and rats.(6) Its presence in the landfill probably results from the disposal of household garbage containing plastics. Compared to the high levels found in plastics themselves, the levels of DEHP found in the leachate and surface water are small.

Aniline is a chemical used as an intermediate in the rubber, plastic and dyestuffs industries. The evidence for its carcinogenicity is described by the International Agency for Research on Cancer as "limited."(8) Only two of ten samples of leachate and surface water analyzed showed the presence of aniline and the levels were low.

1,4-Dioxane is a widely used industrial solvent. It has been shown to be carcinogenic in rats and guinea pigs when administered in the drinking water at concentrations of 5,000 parts per million or more.(9,10) Parts per million concentrations of 1,4-dioxane have been found in several samples, particularly from the leachate collection manhole (Site 32 in Figure 6) where the average of four measurements taken between March 1983 and December 1984 is 10 ppm. Again, by the time material from this site, which is discharged into the sanitary sewer, reaches the sewage treatment plant, the very large degree of dilution by other sewage streams would reduce the level of 1,4-dioxane coming from the landfill to levels that present no hazard to workers.

At other sampling sites, the concentrations of 1,4-dioxane found are much lower, although concentrations in excess of 1 ppm have been found at three leachate sites. Only one of four samples of creek water showed detectable levels of 1,4-dioxane (68 ppb).

Polycyclic aromatic hydrocarbons (PAHs) are produced during the combustion of all forms of organic matter (wood, coal, gasoline, oil, etc.). They are found in charcoal-broiled meat and similar foods.(11,12) The term PAH is a generic name for a large number of individual chemicals containing two or more fused benzene rings.

Several members of this class are carcinogenic (e.g., benzo(a)pyrene), others (e.g., anthracene) are not.(13) PAHs contribute to the carcinogenicity of cigarette smoke and coke oven emissions.

Although the Upper Ottawa Street landfill contains PAHs, and some are leaching out (Table 2), the analyses of sediments from the creek and leachate springs (Table 14) indicate that most of the PAHs detected, and all of the carcinogenic PAHs for which analyses were done, are present at higher concentrations upstream of the landfill than either downstream or in the particles contained in the leachate. This implies that other sources in the area may present a greater risk from PAHs than does the landfill itself.

Similar considerations also apply to PAHs in air. As noted above, PAHs are universal byproducts of combustion, and are released into the atmosphere from gasoline- and diesel-powered vehicles, home and factory chimneys, etc. Because of the relatively low volatility of most PAHs, they are most commonly carried on microscopic particles in the air (soot, smoke particles, exhaust particles, etc.). PAHs from the landfill are also most likely to enter the air carried on particles. In this case, particles from the steel-making wastes used to cover the landfill are the most likely source of PAHs.

There are many possible sources of PAHs in an industrial city like Hamilton, and only relatively low levels of carcinogenic PAHs are being released from the landfill.

Polychlorinated biphenyls (PCBs) are industrial chemicals whose manufacture is no longer permitted, but which were formerly used in electrical transformers. Some electrical equipment still in use contains PCBs. Manufacture of PCBs was banned because they are weakly carcinogenic and can cause various other toxic effects, because their stability had resulted in their becoming widespread environmental contaminants, and because when heated to high temperatures, they can react to form even more toxic derivatives: polychlorinated dibenzofurans and polychlorinated dibenzo-p-dioxins.(14) The concentrations of PCBs in sediment are higher downstream than upstream of the landfill (Table 15) and PCBs are also found in leachate (Table 9). However, higher concentrations of PCBs are observed elsewhere in Hamilton.

The consultants conservatively estimate that the safe limit for exposure to PCBs in soil is 36,000 ppb, a limit 40 times higher than the highest concentrations found at the Upper Ottawa Street landfill.

Other potential carcinogens have been detected at low levels in landfill gases. These include chloroform, 1,2-dichloroethane, trichloroethene and tetrachloroethene (Table 23). However, in the air downwind of the site, these chemicals are either not detectable, or are found only at trace background levels (Table 30).

In summary, the consultants concluded that the assessments of each of the indentified carcinogens suggested that these chemicals are unlikely to pose a substantial risk. The major considerations involved in these assessments were that the concentrations of the detected compounds were for the most part low in comparison to background levels and to other non-landfill sources of the same compounds.

C3. RISK ASSESSMENT OF PAST EXPOSURE

The Committee commissioned Environ Corporation to conduct a study on the feasibility of developing a correlation between past air emissions associated with landfill operations and a possible long-term cancer risk.(16)

The feasibility study was designed to be undertaken in the following steps:

Step 1) review available data on types and quantities of wastes deposited in the landfill, on site operating procedures, and on the results of the chemical analyses;

Step 2) make approximations of emission rates, atmospheric dispersion (see page 163 for atmospheric dispersion study), human dose, and risk for selected chemicals;

Step 3) refine estimates of emission rates, atmospheric dispersion, human dose and risk for selected chemicals.

At the end of each step, provision was made for review of the results before proceeding further. Subject to the satisfactory conclusion of Step 3 and the availability of data, the risk assessment would then be extended to address the range of chemicals present at the site.

The overall feasibility of risk assessment would have been evaluated by two key criteria:

1) estimation of emissions rates must be possible for a substantial portion of the volatile compounds and particulates present at the site;

2) the potential health impacts associated with the estimated emission must be consistent with the symptomology observed in the health studies of landfill workers and area residents.

Only if these criteria had been met would there appear to by any potential for establishing a linkage between past air emissions from the site and long-term health risk.

It was concluded from Step 1 above that the characterization of long-term human health risk (risk of cancer) resulting from past air emissions from the Upper Ottawa Street landfill would not be feasible due to the lack of information on emissions, waste characteristics and site operating procedures.

D. CONCLUSIONS

D1. LEACHATE

Leachate contains a multitude of toxic chemicals, some of them in appreciable amounts. While the levels of individual components are not high enough to be a cause for alarm, no real assessment can be made of the cumulative effect of the mixture. Therefore, it would be prudent to avoid skin contact with (and/or ingestion of) leachate.

D2. SURFACE WATERS

When leachate reaches the Red Hill Creek it becomes greatly diluted. As a consequence, the levels of contaminants found in the creek are sufficiently low so that the risk to human health is very small, provided that contact is limited as assumed in section B2.

This conclusion might also require modification if in the future substantially higher concentrations of these chemicals were found in leachate, surface water or sediment, or if other chemicals that have not appeared in these media to date were to be found. The limited sampling that has been carried out inside the landfill itself does not suggest that this is likely to present a substantial problem.

D3. AIR

The escape of chemicals from the landfill into the air could be of some concern because of the potential for more widespread exposure to these chemicals than occurs following escape into surface water. Fortunately, the levels of hazardous materials released into the air appear to be low, and dilution in the air is rapid and extensive. As a result, chemicals are not detected downwind of the landfill at concentrations higher than those upwind or at distant sites in Hamilton. This means that people living downwind of the landfill are not at any higher risk than those living elsewhere in Hamilton or other comparable industrial cities.

References

1. H.B. Singh, L.J. Salas, R. Stiles, and H. Shigeish, Measurements of Hazardous Organic Chemicals in the Ambient Atmosphere. Report prepared by SRI International for U.S. Environmental Protection Agency, Office of Research and Development EPA - 600/3-83-002. NTIS PB 83-156935, 1983.

2. National Toxicology Program, NTP Technical Report on the Toxicology and Carcinogenesis Studies of Benzene (CAS No. 71-43-2) in F344/N Rats and B6C3F1 Mice (Gavage Studies), NTP-TR 289. NIH Publication No. 84-2545, 1985.

3. National Academy of Sciences, Drinking Water and Health. Washington, D.C., 1977.

4. U.S. Environmental Protection Agency, Health Assessment Document for Dichloromethane (Methylene Chloride). USEPA, Office of Health and Environmental Assessment, Washington, D.C. 20460. EPA/600/8-82/004F, Final Report, February 1985.

5. National Toxicology Program, NTP Technical Report on the Toxicology and Carcinogenesis Studies of Dichloromethane (Methylene Chloride) (CAS No. 75-09-2) in F344/N Rats and B6C3F1 Mice (Inhalation Studies). NTP-TR 306. Board Draft 1985.

6. National Toxicology Program, NTP Technical Report on the Carcinogenesis Bioassay of Di(2-Ethylhexyl)phthalate (CAS No. 117-81-7) in F344 Rats and B6C3F1 Mice (Feed Study). NTP-TR 217. NIH Publication No. 82-1773, 1982.

7. D. Turnbull and J.V. Rodricks, "Assessment of Possible Carcinogenic Risk to Humans Resulting from Exposure to Di(2-ethylhexyl) phthalate (DEHP)," Journal of the American College of Toxicology 4 (1985): 111-145.

8. International Agency for Research on Cancer, Aniline and Aniline Hydrochloride. IARC Monographs on the Evaluation of Carcinogenic Risk of Chemicals to Man. Volume 27, pp 39-61, 1982.

9. International Agency for Research on Cancer, 1,4-Dioxane. IARC Monographs on the Evaluation of Carcinogenic Risk of Chemicals to Man. Volume 11, pp 247-256.

10. National Cancer Institute, Bioassay of 1,4-Dioxane for Possible Carcinogenicity. NCI Carcinogenesis Technical Report Series No. 80, 1978.

11. International Agency for Research on Cancer, Certain Polycyclic Aromatic Hydrocarbons and Heterocyclic Compounds. IARC Monographs on the Evaluation of Carcinogenic Risk of Chemicals to Man. Volume 3. 1973.

12. International Agency for Research on Cancer, Polynuclear Aromatic Compounds, Part 1, Chemical, Environmental and Experimental Data. IARC Monographs on the Evaluation of Carcinogenic Risk of Chemicals to Man. Volume 32. 1983.

13. Dipple, A., Moschel, R.C., and Bigger, C.A.H, Polynuclear Aromatic Carcinogens. In: Searle, C.E. (editor) Chemical Carcinogens. Second Edition, pp 41-163. American Chemical Society Monograph 182, Washington, D.C. 1984.

14. International Agency for Research on Cancer, Polychlorinated Biphenyls. IARC Monographs on the Evaluation of Carcinogenic Risk of Chemicals to Man. 18, (1978): pp 43-103.

15. R.D. Kimbrough, H. Falk, P. Stehr and G. Fries, Health Implications of 2,3,7,8-tetrachlorodibenzodioxin (TCDD) Contamination of Residential Soil. Journal of Toxicology and Environmental Health 14 (1984): 47-93.

16. Environ Corporation, Upper Ottawa Street Landfill Risk Assessment - Feasibility Study, May, 1986.

CHAPTER 10

INTRODUCTION TO THE HEALTH STUDIES

TABLE OF CONTENTS

Page

A. INTRODUCTION 194

B. EPIDEMIOLOGICAL STUDIES 194

- B1. IDENTIFICATION OF EXPOSURE LEVELS 194
- B2. SAMPLE SIZE 195
- B3. CONFOUNDING 195
- B4. BIAS 195
- B5. SELECTION OF CONTROLS 196
- B6. CONCERNS OF THE INDIVIDUAL 196

C. BIOLOGICAL MONITORING AND LABORATORY TESTS 196

- C1. BIOLOGICAL MONITORING 196
- C2. LABORATORY TESTS 197
- C3. PHYSICAL EXAMINATIONS 197
- C4. ADVANTAGES OF THE QUESTIONNAIRE SURVEY APPROACH 198

D. PLAN FOR THE HEALTH STUDY OF THE UPPER OTTAWA STREET LANDFILL 198

- D1. STUDY TEAM 198
- D2. DETERMINING LEVELS OF PAST EXPOSURE 199
- D3. HEALTH SURVEYS 201
  - D3.1 Workers Study 201
    - D3.1(a) Objective of Hypotheses Generating 201
    - D3.1(b) Size 202
    - D3.1(c) Questionnaire Design 202
  - D3.2 Residents Study 202
    - D3.2(a) Objective of Hypotheses Testing 202
    - D3.2(b) Size 202
    - D3.2(c) Modifications to the Questionnaire 203
- D4. MEDICAL CHART ABSTRACTION STUDIES 203
- D5. PERCEPTION OF RISK 204
- D6. ASSESSING THE RESULTS OF THE HEALTH SURVEYS 204
  - D6.1 Workers Study 204
  - D6.2 Residents Study 205

Table | Page

35 Possible Target Sites and Effects of Chemicals Identified at Elevated Levels in Samples Taken in or Near Upper Ottawa Street Landfill Site 200

References 207

APPENDIX 6

Membership of the Advisory Health Group

A. INTRODUCTION

The most commonly used approaches to such health studies of landfill populations involve laboratory tests and biological monitoring, epidemiological studies or a combination of these. A general overview of the approaches will be presented and this will be followed by a description of the study plan developed for the Upper Ottawa Street landfill study.

B. EPIDEMIOLOGICAL STUDIES

Among the various tools that have been developed by epidemiologists for studying the health of populations, the health survey has become an important element in the investigation of the health status of people exposed to chemical emissions. The health survey approach involves collecting by questionnaire the self-reports of individuals in the exposed population and comparing their health status with that of people living in a similar neighbourhood (i.e., controls).* Health surveys are designed to answer the question, 'Is there evidence of an excess of health problems in the population exposed to the landfill?'

Epidemiological studies need to be designed with a view to overcoming problems that could potentially invalidate the results or lead to inappropriate interpretations and these are discussed in the following sections.

B1. IDENTIFICATION OF EXPOSURE LEVELS

Health surveys have caused concern in the scientific community regarding the interpretation of both their positive and negative findings. Some investigators argue that epidemiological studies cannot be used to define cause and effect associations between landfill exposures and illness unless certain preconditions are met. These include: knowledge of the nature and quantities of major chemical emissions from landfills; identification of the probable routes of human exposure (skin, breathing, oral); estimates of individual exposure; identification of high risk subpopulations and the use of specific and sensitive health indicators.(1)

Strict adherence to these preconditions would likely preclude carrying out any health surveys of persons living and working near landfill sites because this type of high quality exposure information simply is not available. Typically, most sites were used for multi-source dumping but records of waste disposal were not kept nor were analyses conducted on landfill contamination of air, surface or ground waters or soil.

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* In this setting, the health surveys were designed as 'retrospective cohort' studies. Workers and residents were identified at the time of first 'exposure' to the landfill site, and followed forward in time through their retrospective recall of various health problems.

This lack of exposure information makes it impossible in most instances to identify target health problems which would be expected to be caused by exposure to certain levels of specific chemicals. At the same time, many of the health problems and symptoms being identified in studies of landfill populations are of a non-specific nature such as eye irritation, sore throats, fatigue and headaches, further limitating the potential for an epidemiological study to identify exposure to landfill contaminants as the cause of illness.

In the absence of high quality exposure informaton, investigators have used duration of residence and proximity to the landfill in place of individual estimates of chemical-specific exposure. They have also used non-specific environmental health indicators such as reproductive and developmental effects, respiratory and skin problems and irritant symptoms as outcome variables. While these compromises may reduce the validity of an epidemiologic survey, they do not pose insurmountable problems.

B2. SAMPLE SIZE

A difficult statistical problem shared by many epidemiological landfill investigations is the small size of the exposed populations. This is especially serious when the incidence of the health effect in the unexposed population is rare. For example, the number of people working and living near landfills is often too small to give health surveys sufficient statistical power to detect cancers or birth defects.

B3. CONFOUNDING

A problem common to epidemiological studies, particularly those concerned with landfills, is the mixing of health effects caused by exposure with those associated with other (confounding) factors. Confounders include age, sex, marital status, socioeconomic status and especially the so-called lifestyle factors of smoking, drinking, diet, etc. Methods have been developed, however, which allow the epidemiologist to take account of confounding effects in computing disease rates.

B4. BIAS

The control of bias is a necessary feature of epidemiological studies. Bias may arise in a number of ways, many of which are unique to the particular situation. For example, mobility may introduce a migrator selection bias in the identification of the study group for the exposed population. If ill health relating to landfill exposures caused persons to move away, it may be that persons who truly experienced the health effects could be lost to the study.

The identification and followup of the residential population can be complicated by a high rate of in and out migration from the housing developments adjacent to the landfill.

Another especially difficult form of bias to control is recall bias, which arises from the fact that members of the exposed group may be more sensitive than a control population to the state of their health because of knowledge that they have been exposed to a potential cause of disease.

B5. SELECTION OF CONTROLS

Ideally, the comparison group should be similar to the study group in terms of such factors as age, race, sex, socioeconomic status, lifestyle, etc. If the control group is 'identical' to the landfill residents in every respect, any excess of health problems observed in the landfill residents would be expected to be associated with exposure to the site.

B6. CONCERNS OF THE INDIVIDUAL

Epidemiological studies such as the health surveys conducted at landfill sites provide information only about populations and not about individuals. It is usually not possible to identify which people developed the health problems resulting from landfill exposure as opposed to the persons who developed the same health problems for other reasons. For example, with chronic bronchitis, the prediction (based on the incidence of the disease in the control group) would show a certain number of landfill area residents would be likely to have chronic bronchitis because of general factors such as age, smoking, and so forth that are unrelated to the landfill. It may be observed, however, that an excess number of landfill area residents actually have this health problem. Therefore, only some of the residents contacted chronic bronchitis from the landfill exposure and it is impossible to know which persons out of the entire group these may be.

C. BIOLOGICAL MONITORING AND LABORATORY TESTS

C1. BIOLOGICAL MONITORING

Early in its work, the Committee considered the use of biological monitoring (i.e., the direct analysis of body fluids or tissues for toxic chemicals). While this approach is conceptually appealing since it is the most direct way of trying to determine whether or not a particular population has been exposed to a toxic chemical, many practical difficulties limit its usefulness.(2) These include the need to have either: 1) a good indication of the chemical to which a population has been exposed, and thus the chemical to be looked for in the analysis, or 2) clear evidence that the exposed population is suffering from a disease which could have been caused by a particular chemical or chemicals. In situations in which neither of these conditions is met, there is little use in embarking on a 'fishing trip'.

Many chemicals do not accumulate in body fluids, while other compounds such as PCBs and certain pesticides are found in everyone's tissues. Further, large variations in the levels of chemicals are found in unexposed control subjects making the detection of differences between control and exposed population difficult. These variations cause a level of background 'noise' and because of this noise, there sometimes appear to be differences between the populations when, in fact, examination of a larger sample of the same population would show that there is no difference. Statisticians attempt to minimize this problem by insisting on a low probability that the results could have occurred by chance alone before they can be called 'statistically significant'. In general, probability values no higher than five per cent (or one chance in 20, or $p = 0.05$) are required when a single comparison is being made.

As a consequence of this situation, if 20 laboratory tests are being used to compare two populations, one of these tests will, by chance, appear to show a significant difference between the groups. As the number of comparisons being made is increased, an increasing number of 'false positives' will turn up. The problem is, of course, that there is no way that a study can distinguish between true and false positives. To try to deal with this situation, statisticians often require that when multiple comparisons are being made, p values lower than 0.05 be required before significance is claimed. Nevertheless, the likelihood of false positives when large numbers of comparisons are being made means that for rigorous studies a limited number of tests selected on the basis of known exposure and/or known disease should be employed.

There is also the problem of the possible reluctance of people (especially the unexposed controls) to undergo invasive tests. This may not be a problem with urine and blood, but could make meaningful tests on fat or other tissue impossible. The long period between the time of maximum exposure while the landfill was in use and the beginning of the study also decreases the potential usefulness of biological monitoring. Given these factors, it was decided not to consider a program of biological monitoring of landfill workers or residents at the Upper Ottawa Street site until after the results of a questionnaire survey were available.

C2. LABORATORY TESTS

Similarily, laboratory tests (i.e., the analysis of body fluids or tissues for normal body constituents, or tests for particular body functions) while superficially attractive, suffer from many of the same limitations as biological testing. There is agreement that indiscriminate use of such tests in the absence of an indication of the chemicals or diseases involved is unwarranted.(3,4) The Committee concluded that the decision whether or not to use laboratory tests should also await the results of a questionnaire survey.

C3. PHYSICAL EXAMINATIONS

The Committee also considered the possibility that physical examination of persons exposed to the landfill would be useful in determining whether or not their health had been affected by their exposure. For the reasons similar to those given above it was decided not to consider a program of clinical examinations until the survey results were known.

C4. ADVANTAGES OF THE QUESTIONNAIRE SURVEY APPROACH

Effort was made to maximize the validity of the health questionnaire survey by a series of strategies that are described in the following section of this chapter. This approach corresponds to the strategy recommended by other investigators.

> "In contrast to the methods used by physicians to develop a diagnosis of disease in individuals, the initial detection of a disease in populations near a chemical disposal site is often best accomplished by other means. Where the history and physical examination is often not practical for large groups of individuals, pertinent information can be gathered more efficiently and effectively with a well constructed questionnaire. Laboratory testing as an initial screening procedure is usually not beneficial. Preliminary epidemiologic studies frequently find only non-specific complaints such as ambient odours, headaches, dizziness, fatigue, loss of libido, or menstrual irregularities. In such instances, careful detailed clinical and laboratory studies are seldom justified."(5)

D. PLAN FOR THE HEALTH STUDY OF THE UPPER OTTAWA STREET LANDFILL

D1. STUDY TEAM

The Commttee established an Advisory Health Group to assist in designing health studies of landfill workers and area residents. The Advisory Health Group was chaired by Dr. William Goldberg. The members of this Group include Dr. David Muir, Dr. Michael Newhouse, Dr. Andrew Harper and Dr. Michael Achong (Appendix 6). In addition to their central role in providing advice on the design and execution of the health studies, the involvement of members of Hamilton's medical community also benefitted the study in terms of eliciting support for the study generally and from the physicians whose participation was required in the medical chart abstraction studies.

The workers and residents health studies were carried out by a team of research consultants including Dr. Clyde Hertzman, an epidemiologist at McMaster University and now Director, Division of Occupational and Environmental Health at the University of British Columbia; Dr. Joseph Highland, a biochemist and principal of Environ, a health and environmental consulting firm located in Washington D.C. and Princeton, New Jersey; Dr. Joel Singer, a biostatistician at McMaster University; and Michael Hayes, an urban geographer at McMaster University. The contract for the field work for the surveys was awarded through public tender to Hamilton Opinion Research Centre Limited.

A number of experts across Canada and the United States were also involved as external referees in reviewing the protocols for the health studies and the final reports of the findings. (Appendix 7)

D2. DETERMINING LEVELS OF PAST EXPOSURE

The actual chemical exposures experienced by landfill workers and area residents before the Upper Ottawa Street landfill was closed in 1980 cannot be documented. The absence of reliable information about the types and quantities of wastes deposited at the site is discussed in Chapter 4. The major approach that was undertaken to attempt to get some insights involved extensive chemical analyses of air, landfill gas, leachate, surface and ground waters. The health studies were then designed with the view that workers and residents had likely been exposed in the past to the chemicals that could be currently detected, regardless of the current concentrations. The shortcoming of this approach is acknowledged but it is the only available means of developing reasonable assumptions about past exposures for situations like the Upper Ottawa Street landfill.

A summary list of the compounds detected at the landfill site (in concentrations higher than drinking water criteria) and their potential health effects should exposure have occurred at sufficiently high levels and for sufficiently long periods of time is shown in Table 35. This list, which was first developed in 1983 and updated for this Report, was used only to provide guidance to designing the health survey questionnaires in the absence of good exposure information. The list was derived from a review by toxicological consultants of the inherent toxic properties of chemicals to which people may have been exposed. This information was helpful because it demonstrated the need for comprehensive health surveys to look for a wide variety of possible health effects as contrasted to a survey focussed on only a few types of toxicity.(6)

In the absence of reliable exposure information, other health studies of landfill exposure have used duration of residence and proximity to the landfill as surrogate measures of exposure.(7,8) This was the approach taken with the health studies of Upper Ottawa Street landfill workers and residents.

The indirect measurements of exposure used in the workers study were: duration of exposure (i.e., the number of hours per week spent working at the landfill); time since first exposure to the landfill; and onsite exposure versus exposure at sites adjacent to the landfill. The distinction between those who worked directly on the landfill and those who worked at the public works yard or fire training centre adjacent to the site provided the best available index of intensity of exposure.

In the residents study, gradient analyses were carried out to determine whether an increased incidence of health problems was related to duration of exposure to and distance of household from the landfill. Long-term exposure was defined for residents who had lived near the landfill for three or more years during 1976-1980, the period of highest volume disposal of industrial waste. Short-term

Table 35:

Possible Target Sites and Effects of Chemicals Identified at Elevated Levels in Samples Taken In or Near Upper Ottawa Street Landfill

Chemicals	Effects																											
	Eye irritation	Eye damage	Skin irritation	Skin damage (chloracne)	Allergic sensitization	Upper respiratory tract irritation	Lung damage	Liver damage	Kidney damage	Central nervous system depression	Central nervous system damage	Peripheral nervous system damage	Blood cell disorders	Methemoglobinemia	Immunological effects	Spleen damage	Thymus damage	Cardiovascular effects	Gastrointestinal effects	Pancreatic damage	Endocrine disorders	Bone disorders	Reproductive effects	Embryotoxicity	Teratogenicity	Mutagenicity	Carcinogenicity	Tumor promotion
Organic Chemicals																												
Aliphatic alcohols	+		+			+		+	+		+																	
Alkyl benzenes	+		+			+				+																		
Alkyl ketones	+		+					+	+	+								+										
Alkyl phenols	+		+			+	+	+	+	+	+					+		+	+	+								
Aniline														+													+	
Aromatic acids	+		+																									
Benzene	+		+							+			+		+			+								+	+	
Benzothiazole					(+)																							
Carboxylic acids	+		+			+																						
Cresols	+		+																									
1,4 Dichloro-benzene	+		+			+		+	+				+															
1,2 Dichloro-ethane	+																											
Dichloromethane	+		+					+		+														+				
1,4-Dioxane	+		+			+		+	+																		+	
PAHs	+	+	+			+		+					+											+	+		+	+
PCBs				+			+	+							+		+		+				+	+	+	+	+	
Phenol	+		+			+	+	+	+	+	+	+						+	+									+
Phthalate ester—[Di(2-ethylhexyl)]	+		+					+															+				+	
Phthalate esters (other)	+		+																									
Tetrachloroethene	+		+			+		+	+	+									+					+			+	
Tetrahydrofuran			+			+		+	+	+								+										
Trichloroethene	+		+							+					+			+								+	+	
Inorganic Chemicals																												
Aluminum																			+			+						
Chromium	+		+		+	+	+						+						+									
Copper								+	+		+					+			+									
Iron							+												+									
Lead									+		+	+	+		?			+			+		+	+			+	
Manganese					+						+																	
Nickel					+		+	+	+	+									+				+				+	
Zinc			+					+					+						+				+					

NOTES: a. Parentheses () indicate that no data were found for the particular chemical, but closely related chemicals have the effect noted. A question mark (?) indicates that the evidence for a particular effect is not conclusive.

b. Where classes of chemicals are indicated, not all members of the class cause all the effects noted.

exposure was defined for residents who had lived near the landfill for less than three years during the same period. Non-exposed control groups were selected from a comparable neighbourhood remote from a landfill.

A decision was made to confine the geographical area of the study to within 750 metres around the landfill site. This decision was based on considerations of sample size, ease of analysis and cost. The zone of exposure so identified was divided into two bands which made it possible to plan a three point analysis of gradient of exposure by proximity to the site: households located within 500 metres of the site; those located 500 to 750 metres from the landfill; and the control housholds. A second analysis of proximity to the landfill involved the use of the exact distance of each household from the site.

D3. HEALTH SURVEYS

The type of epidemiological study design that was used in the health studies at the Upper ottawa Street landfill is a retrospective cohort survey in which the incidence rates of health problems in landfill workers and area residents were compared to those of control groups of workers and residents who had not worked or lived near the landfill. The main objective of the health surveys was to identify whether or not any excess in health problems, possibly associated with exposure to the landfill, especially during the period of high volume disposal of liquid wastes (1976-1980), could be observed in the landfill groups as compared to the contols.

D3.1 Workers Study

D3.1(a) Objective of Hypotheses Generating. Given that little was known about the health status of workers or their exposure to the landfill, the workers health survey was necessarily an 'hypotheses generating' study. This means that the workers study was designed to identify health problems in workers that could possibly be associated with working at the landfill. The identified problems would subsequently be tested in a study of residents but it could not be concluded definitively from the workers study that the landfill was the cause of any observed health problems. If, however, the same health problems were identified in workers and residents, this would provide evidence of a possible association with the landfill.

The Committee and its Advisory Health Group had decided that a health study of landfill workers should precede the residents health study. The reasons for this were:

1) the workers represent a potentially high dose exposure subgroup, and might therefore be a sensitive indicator of any potential health impact associated with exposure to the landfill;

2) apparent increases in specific health problems found in a workers study could receive detailed examination in the residents study, thereby reducing the statistical problem of multiple comparisons inherent in the analysis of a general health survey;

3) consistent results from two separate health surveys with different designs might be more credible than one study which tried to combine workers and residents in one protocol.

D3.1(b) Size. The study population consisted of 197 men. Less than one-half this number of persons actually worked on top of the landfill. The rest experienced less intense exposure while working in the adjacent public works yard or fire training centre. Landfill workers who had moved away from the Hamilton Region were followed up across Canada.

A control group of 235 persons, comparable to the landfill workers except they had never worked near a landfill, was identified. The study team worked with local governments to identify, as control subjects, municipal outdoor workers with no known landfill site exposure, or regular exposure to herbicides and pesticides. It was also necessary to match by the status of currently employed and retired.

D3.1(c) Questionnaire Design. No satisfactory questionnaires existed that could have been adapted for this study, consequently a special questionnaire was designed by the research team. It was not possible to identify a short list of health problems of particular interest because little was known about the chemical exposures experienced by workers before the landfill was closed in 1980. The questionnaire that was eventually designed consisted of items that inquired about all major aspects of a person's health that could be associated with environmental exposures and also permitted respondents to report any other health problems they wished. Health conditions thought to be unrelated to chemical exposure were included as decoy questions in order to test the specificity of the association between self-reported health problems and a chemical cause. This approach was seen as being effective in detecting a wide range of possible health effects related both to the chemicals currently identified in the landfill and to chemical exposure generally. Professional interviewers began administering the health survey questionnaires to workers in the workers' homes homes in the spring of 1983.

D3.2 Residents Study

D3.2(a) Objective of Hypotheses Testing. Work began on the design of the residents study before the analyses of the results of the workers study were completed. The preliminary findings from the workers study, however, provided a sufficient basis for defining the target health problems (i.e., main hypotheses) to be tested in the residents study.

D3.2(b) Size. Few residents lived in the landfill neighbourhood before 1973 and the majority of residents moved into the area after 1976. The residents eligible for the study were determined from tax assessment rolls and eventually

1114 households were identified. These included persons who currently reside near the landfill, 'recent' residents who moved in after the landfill was closed, and former residents who moved out of the area. Approximately two-thirds of the households that had moved away from the landfill neighbourhoods were found within Hamilton and surrounding municipalities through driver license records and local telephone directories. Efforts were made to include all former landfill area residents in the study in order to mitigate a possible migrator selection bias.

Selection of controls for the residents health study was planned with the objective of achieving comparability in family size, age distribution and socioeconomic status, since these factors generally correlate closely with the occupational and personal health risk factors that could confound the outcome of the study. A neighbourhood located approximately eight kilometers west of the landfill was selected for comparison and 636 households in it were identified as controls.

D3.2(c) Modifications to the Questionnaire. The questionnaire used successfully to survey the workers was adapted for the residents study with changes to obtain more detailed information about pregnancy and childbirth and to examine the health of children. Interviewers began administering the questionnaire in the spring of 1984. The questionnaire was designed to be completed by the female head of the household for all members of her family.

D4. MEDICAL CHART ABSTRACTION STUDIES

Detailed protocols for medical chart abstractions were designed for the health studies of landfill workers and residents, for the purpose of ascertaining recall bias, which can be measured by comparing the health problems people report on the questionnaires with their physicians' records. The objective of chart abstraction in the workers study was to verify the accuracy of self-reports of individual respondents. The objective in the residents study was to ascertain the amount of recall bias through a comparison of general trends of over- and under-reporting between landfill residents and controls.

D5. PERCEPTION OF RISK

The primary focus of the health studies was the investigation of an association between any excess of health problems and living and working near the landfill. The difficulty of relating any observed effects to unknown past exposures suggested that causes other than direct chemical exposure could also be legitimately argued. An alternative cause could be the perceptions of people living and working near the landfill that the site was a threat to their health. If people believed that being near the landfill was a health risk, it is possible that such anxiety could produce physical health problems. It was the opinion of the Committee that ill health caused by perception or fear of the landfill was as real as ill health caused by actual chemical exposures. It was recognized that distinguishing between the two possible causes could be extremely difficult.(9,10,11)

D6. ASSESSING THE RESULTS OF THE HEALTH SURVEYS

Given the difficulties of interpreting the results of epidemiological surveys generally and in particular those investigating landfill site exposures, it was decided that the validity of the results obtained from the health surveys of landfill workers and residents would be evaluated according to multiple criteria. These were identified in conjunction with the plans for analyzing the results of the workers and residents health surveys but they were set before the results of the analysis of the data were available.

D6.1 Workers Study

In the case of the workers study, the focus was on evaluating the credibility of associations found between exposure to the landfill site and health problems found in excess in landfill workers (compared to controls) by five criteria, which would form an overall credibility rating.

The five criteria developed for the evaluation were:

a) biological plausibility - toxicological evidence that the identified health conditions could be caused by exposure to toxic chemicals in the landfill;

b) statistical strength - meeting a level of relative risk in which landfill workers were at least twice as likely as controls to develop a health problem. The probability (p value) of an increased relative risk occurring by chance would have to be less than five in 100;

c) recall bias - evidence of recall bias would be obtained from medical chart abstractions;

d) time cluster - the periods of time during which landfill workers first developed the identified health conditions (if the conditions were related to short-term acute exposure) would be most credible if they corresponded to the years of high volume waste disposal at the site (1976-1980);

e) risk gradient - evidence of a statistically significant 'linear trend', which would show that the risk of developing the health problem was related to intensity of exposure as demonstrated by higher risks for onsite landfill workers as compared to workers adjacent to the landfill, whose risk would be higher than that of controls.

The overall rating based on these five evaluation criteria would rank the health conditons identified in excess in landfill workers as being of high, moderate, or low credibility. The health conditions ranked as highly credible hypotheses would be more likely to have been caused by exposure to the landfill site than those ranked moderate or low. The health problems that received high and moderate credibility ratings would provide the main hypotheses to be tested in the residents study.

D6.2 Residents Study

Nine criteria were developed to assess the validity of the association between health problems, which were found to be more prevalent in landfill area residents than in controls, and living near the landfill:

a) relative risk - landfill area residents would have to be at least 1.5 times as likely as controls to develop a health problem in order to meet an acceptable level of relative risk;

b) probability value - the probability of the relative risk occurring by chance would have to be less than one in one hundred to be acceptable;

c) consistency - there should be reasonable consistency between the results of the health surveys of residents and workers;

d) gradient of risk - evidence of a higher relative risk for those who live in close proximity to the landfill or had longer duration of residence would support an association with exposure to landfill chemicals;

e) migrator bias - the health of persons who moved away from the landfill neighbourhood might explain differences observed between current landfill residents and controls;

f) general health status - evidence that the health status of people who moved into the landfill area after the site was closed was not different than that of the controls would support the argument that any observed differences might be associated with landfill exposure;

g) period of risk - if the identified health problems of landfill area residents first occurred before the landfill was closed in 1980, this would support an association with landfill exposure, particularly if the health problems were related to short-term acute exposure;

h) decoy questions - if the health problems reported by landfill area residents were confined to those observed in landfill workers or those which could be related to chemical exposure and not to problems unrelated to chemical exposure (prespecified decoy questions), this would support an association with landfill exposure;

i) recall bias - the medical chart abstraction study would provide evidence of whether landfill area residents over or under-reported their health problems on the questionnaire.

Using these criteria, the results of the residents study could be evaluated for valid associations between living near the landfill and the incidence of certain health problems.

References

1. P.J. Landrigan, "Epidemiologic Approaches to Persons with Exposures to Waste Chemicals," Environmental Health Prospectives 48 (1983): 93-97.

2. K. Kreiss, "Studies on Populations Exposed to Polychlorinated Biphenyls," Environmental Health Prospectives 60 (1985): 193-199.

3. R.H. Hill Jr., "Effects of Polyhalogenated Aromatic Compounds on Porphyrin Metabolism," Environmental Health Prospectives 60 (1985) 139-143.

4. P.S. Guzelian, "Clinical Evaluation of Liver Structure and Function in Humans Exposed to Halogenated Hydrocarbons," Environmental Health Prospectives 60 (1985): 159-164.

5. Universities Associated For Research and Education in Pathology, Inc., Health Aspects of the Disposal of Waste Chemicals, Draft of a Final Report to be published in the spring of 1986 by Pergamon Press Inc., Elmsford, New York: p. 4-6, (Hereafter cited as UAREP).

6. Environ Corporation, Preliminary Summary of the Inherent Toxic Properties of Selected Substances Tentatively Identified at the Upper Ottawa Street Landfill. January - February, 1983.

7. K.P. Satin, et al., "Health Effects in a Population Living Near an Acid Petroleum Sludge Disposal Site in California," Abstract No. 254 from the Tenth Scientific Meeting of the International Epidemiological Association (Vancouver, 1984).

8. B. Paigen, L. Goldman, J. Highland and M. Magnant, "Growth and Health in Children Living Near a Hazardous Waste Site", For presentation at Society for Pediatric Research (May, 1983).

9. UAREP, p. 5-21. (see reference 5)

10. R. Tessler, D. Mechanic, "Psychological Distress and Perceived Health Status," Journal of Health and Social Behaviour 19 (1978): 254-262.

11. D. Mechanic, P. Cleary, J. Greenley, "Distress Syndromes, Illness Behaviour, Access to Care and Medical Utilization in a Defined Population," Medical Care 20 (1982): 361-372.

PART 3

HEALTH STUDIES

Introduction to the Health Studies

Survey of Health of Workers

Survey of Health of Landfill Area Residents

CHAPTER 11

A SURVEY OF THE HEALTH OF PERSONS WORKING AT OR NEAR THE UPPER OTTAWA STREET LANDFILL

Table of Contents

Page

A. INTRODUCTION 212

B. MATERIALS AND METHODS 213

B1. IDENTIFICATION OF THE STUDY POPULATION 213

B1.1 Study Subjects: Upper Ottawa Street Landfill Workers 213
B1.2 Controls: Comparison Workers 213

B2. THE DEVELOPMENT AND ADMINISTRATION OF THE QUESTIONNAIRE 214

B2.1 Content of the Questionnaire
B2.2 Administration of the Questionnaire 216

B3. MEDICAL CHART ABSTRACTION 216

B4. ANALYSIS OF THE DATA 217

B4.1 Approach 217
B4.2 Main Analysis 217
B4.3 Data Relating to Recall Bias 219
B4.4 Subanalyses 219

C. RESULTS 220

C1. DESCRIPTIVE STATISTICS 220

C1.1 Rates of Response 220

C1.2 Comparability of Groups 220

C1.2(a) Age Distribution 220
C1.2(b) Selected Sociodemographic Variables 220
C1.2(c) Education Status 220
C1.2(d) Family Income 221
C1.2(e) Drinking Habits 221
C1.2(f) Smoking Habits 221
C1.2(g) Exposure to Toxic Substances 221

Page

C2. MAIN ANALYSIS 221

C3. SUBANALYSES 225

C3.1 Time Clustering 225
C3.2 Risk Gradient with Duration of Exposure and Time Since First Exposure 225
C3.3 Risk Associated with Onsite Exposure Versus Exposure Adjacent to the Landfill 227
C3.4 Correlations between Health Conditions 227
C3.5 Differences in Health Status at Time of Interview 227
C3.6 Other Health Problems 230
C3.7 Mortality 232
C3.8 Comparisons Using Canada Health Survey Questions 232
C3.9 Quality of Self-Reported Health Histories 233

D. **CONCLUSIONS** 233

References 238

Tables Page

36 The Risk of Developing Health Conditions Associated with Working at or Near the Upper Ottawa Street Landfill Site 222

37 The Years of Highest Risk (for Landfill Workers as Compared to Controls) for Developing Health Conditions (in Terms of Events per 1,000 Person Years) 226

38 The Period of Highest Risk (for Landfill Workers as Compared to Controls) by Number of Years Since First Exposure 228

39 The Risk Associated with Gradient of Exposure for Persons Who Worked Onsite, and Adjacent to the Landfill, and for Controls 229

40 Relative Prevalence of Selected Health Conditions at Time of Interview 231

41 A Comparison of Medical Chart Abstraction Results for Over-Reporting by Selected Health Conditions 234

Table Page

42 An Evaluation of the Association of Specific Health Problems and Working at or Near the Upper Ottawa Street Landfill 237

A. INTRODUCTION

This chapter discusses the design and conduct of a health survey of a cohort of persons who worked at the Upper Ottawa Street landfill and are presumed to have been exposed to toxic industrial wastes deposited at the site.(1)

The design of the workers' health study was constrained by three factors: the quantities and types of chemical wastes to which workers were exposed were essentially unknown; there was uncertainty about which target health problems should be investigated given the lack of exposure information; and only a relatively small number of workers experienced direct, continuous exposure to the landfill.

Within these limitations, the workers' health study was designed with three objectives: to describe the current and past health problems of workers at the site during and after the time liquid industrial waste was deposited there; to identify excesses in illness and death among workers that might be associated with these exposures; and to generate hypotheses regarding the possible effects of exposure to the landfill that could be used in the design and analysis of a study of residents in the area.

The strategy adopted was that the study of landfill workers should precede that of landfill residents. If there were any health conditions associated with landfill exposure, it was likely that they could be observed more readily in landfill workers than in residents because the former had longer term direct exposure to the wastes, particularly the liquid industrial wastes. Therefore, the results of the workers study would provide target health problems or hypotheses to be investigated in the subsequent residents' health study. If similar health problems were reported by both landfill workers and residents, the linkage between the two health studies would add credibility to the evidence that the health problems identified were caused by exposure to the landfill.

The workers' study involved administering questionnaires and abstracting the medical charts of Upper Ottawa Street landfill workers and a comparison group of municipal workers employed at locations other than landfills.

This chapter discusses the methods, results, and conclusions of the workers study. In the methods section, the identification of the study population, the development of the questionnaire and of the medical chart abstraction study and the plan for data analysis are described. The results section presents the rates of response, the comparability between landfill workers and controls and the numerous analyses that were carried out. The conclusions focus on assessing the credibility and biological plausibility of identified health conditions whose association with exposure to the landfill site was subsequently examined in the residents study.

B. MATERIALS AND METHODS

B1. IDENTIFICATION OF THE STUDY POPULATION

B1.1 Study Subjects: Upper Ottawa Street Landfill Workers

Neither the City of Hamilton nor the Region of Hamilton-Wentworth kept records that enabled a systematic identification of a cohort of former landfill site workers. However, the Region did provide the names of 20 employees and 16 licensed salvage pickers who had worked at the Upper Ottawa Street landfill. Through telephone contact with this initial group, other persons who had worked at or near the landfill were identified. Four different exposed groups were defined: landfill site employees of the Region; landfill site employees of the City of Hamilton; salvage pickers; and firefighters who were periodically stationed at a nearby training facility.

All names were checked against the Region and City personnel records, and the names of other workers with similar job descriptions were added to the list. The names of additional salvage pickers were confirmed by telephone or by the agreement of two or more salvage pickers that an individual had worked at the landfill. The names of firefighters were supplied by supervisory personnel. By the time new leads stopped coming, the cohort had grown to 197 "landfill" workers: 66 regional employees (including five deceased), 102 city employees (nine deceased), 22 salvage pickers (seven deceased), and seven firefighters. Although some short-term workers may have been missed, it is unlikely that many long-term workers remained unidentified.

B1.2 Controls: Comparison Workers

The City of Hamilton and four other municipalities within the Region of Hamilton-Wentworth (i.e., Ancaster, Dundas, Flamborough and Glanbrook) provided the names of all their outdoor workers with no known exposure to the landfill site or to herbicides and pesticides. The four outlying municipalities also supplied the names of retired outdoor workers. A list of former outdoor workers was compiled by the City's personnel department, but the study team was not permitted to approach these individuals directly because of concern about confidentiality. The City, however, did mail out requests to a random one in two sample of these former employees asking them to contact the study investigators. Only a few responses were received. The study team was then permitted to contact the other half of the list directly. An adequate response rate was obtained; in total 235 names were eventually compiled. The control group consisted of street and sanitation workers who were likely to share with the exposed landfill workers any health-related selection factors that led to outdoor work. The wage scales of the two groups were also expected to be similar.

B2. THE DEVELOPMENT AND ADMINISTRATION OF THE QUESTONNAIRE

B2.1 Content of the Questionnaire

The original plan was to modify a questionnaire that had been used in other environmental health surveys. None of those evaluated was considered suitable: there was no evidence available that they were valid or reliable; they did not fully cover the concerns of this study; and the questions were open-ended and, consequently, not easily quantifiable.* The available questionnaires were used, therefore, as a data bank, and relevant items were rephrased and reorganized to meet the needs of this study.

Three groups of health problems were of particular concern: (1) conditions that appeared, from a 1978 survey conducted by the Upper Ottawa Street Residents Association, to be more common among landfill residents than a control group: skin rashes, frequent colds, kidney problems, frequent bladder infections, sore throats, headaches, earaches, nervousness, and unspecified "bleeding;"(2) conditions associated with the more than 100 toxic chemicals tentatively identified at the Upper Ottawa Street site, which could potentially affect every organ system of the body (page 200); (3) and finally, groups of conditions, which through work done elsewhere, have generally been associated with exposure to toxic industrial substances. These effects include respiratory and skin conditions, which are diseases of the organs that serve as entry routes for toxic substances, narcotic and anesthetic effects, which are associated with exposure to volatile organic chemicals, cancer, and reproductive problems.**

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* Among those reviewed were: New Brunswick Employee Health Status Survey; Hardeman County, Tennessee questionnaire; New York State Department of Health Love Canal Survey; The Centres For Disease Control's Frayser Tennessee questionnaire; and questionnaires from Marvin Legator and Rosalie Bertel.

** Study power was low with respect to specific cancers and reproductive effects. The maximum time since first exposure for workers was 18 years, which is less than the 20-year latent period often encountered with occupational cancer. Nonetheless, this information was collected in case a strong, unsuspected association between a cancer or reproductive problem and landfill exposure was found in the survey, and to provide baseline information for any possible future studies.

The questionnaire finally developed included 73 questions, which covered the following subjects:

a) residential characteristics
b) current sources of drinking water
c) recent use of health services
d) disability days
e) cigarette and alcohol use
f) job history (not including the landfill)
g) history of exposure to specific toxic substances in non-landfill jobs and hobbies
h) long-term health problems
i) acute and chronic health problems from before 1965 until the date of interview
j) history of work injuries
k) reproductive history
l) detailed job history at the landfill
m) socio-economic status (i.e., education, income, ethnic origin, language)

There were four types of questions: those intended to elicit information regarding the comparability of the two study groups (i.e., a-g, j, and m in the above list), questions directly concerning exposure to the landfill site (l), health questions for hypothesis generation (i,k), and Canada Health Survey* questions on chronic disease.

The health questions,which were grouped by organ system, included many items which were not thought to be related to environmental exposures. These decoy questions were included to distract respondents from those items which were of particular relevance to the study, to allow them to select the best description of their health problems from a series of related items, and to find out whether potential differences in health were confined to environmentally related problems. Respondents were also asked to state the year in which each health problem began and whether or not it had persisted until the time of interview.

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* The Canada Health Survey was conducted by Health and Welfare Canada in 1978-79. It was designed as a 'baseline' survey of the health status of Canadians and was to be the first of a series of surveys to assess changes in health status. Funding was discontinued after the initial survey was conducted.

B2.2 Administration of the Questionnaire

Because of the length and complexity of the questionnaire, the investigators decided that it should be administered in a face-to-face interview rather than a telephone interview. The interviews, which took about 90 minutes including the time required to complete consent forms for the examination of medical charts, were conducted in the respondents' homes during the spring of 1983. Because of the way subjects of the study had been identified and the publicity surrounding the landfill site the interviewers knew whether a respondent was a landfill worker or a control. Questions regarding work experience at the landfill were confined to the end of the questionnaire to avoid direct discussion of landfill site issues early in the interview. Possible bias of the interviewers was reduced by not informing them of the significance of specific health questions and instructing them to limit themselves to a standardized set of responses when asked by the respondents for further information.

B3. MEDICAL CHART ABSTRACTION

In order to determine whether or not the exposed workers' concern about working at a liquid industrial waste disposal site had influenced them to report more problems with their health than the workers in the control group, the records of all family physicians named by the subjects of the study were examined. Each condition reported by the respondent was identified on a separate reported condition form attached to the questionnaire.

Four experienced nurses, who were unaware of the exposure status of the study subjects, reviewed the respondents' medical charts in the family physicians' offices. The nurses were asked to determine whether the condition reported in the questionnaire was confirmed, possibly confirmed, or not confirmed in the physicians' charts, and to provide evidence for their decisions.

The abstractors were also required to characterize each condition by the most appropriate of nine possible relationships between the information in the medical chart and the complaint reported. Two of these relationships represent "confirmation": 1) where the condition reported in the interview was found essentially verbatim in the medical chart of the worker's physician and 2) where the diagnosis in the chart necessarily included the symptoms or diagnosis reported during the interview. Four "possibly confirmed" categories were developed to fit situations where any distortions and inadequacies of the questionnaire and the abstraction process might have biased the confirmation process toward respondent over-reporting. Three categories of "non-confirmation" were included, two of which represent shortcomings of the abstraction process (i.e., situations in which the medical chart did not cover the year in which symptoms reportedly began, or where the chart was unreadable), and one which represented over-reporting (i.e., cases in which no diagnoses or symptoms were recorded in the chart that were consistent with or suggestive of the problem reported). The abstractors were instructed to use their own judgment in deciding how conflicts between the date the respondents reported the onset of symptoms and the date noted on the chart might affect confirmation.

The completed "reported condition" forms were checked by the study team for internal consistency between the choice of confirmation category and the evidence provided; only five percent were changed, and most of these involved only change of category, not of the status of confirmation.

The nurse abstractors also completed an unreported condition form, which listed 24 health problems taken primarily from the Canada Health Survey. They recorded on this form information found in the charts that indicated any health problem not reported by respondents.

The information abstracted from the medical records of the study subjects made it possible to calculate the proportion of confirmed, possibly confirmed, and unconfirmed reported conditions and thus to compare over-reporting between the exposed workers and the controls in a search for recall bias.

B4. ANALYSIS OF THE DATA

B4.1 Approach

The data were analyzed in three phases. The first phase assessed the validity of comparing the exposed workers with the non-exposed workers used as the control group. In the second phase, all individual health conditions or biologically related clusters of conditions were deemed to warrant further analysis if there were a 50 per cent or greater difference in the incidence (not adjusted for age or follow-up time) between exposed workers and workers in the control group, and where there were at least 15 events in total. The third phase consisted of subanalyses that were carried out to answer specific questions.

In these analyses, all major sociodemographic variables and other confounders in the data set were compared between exposed workers and controls.

B4.2 Main Analysis

In the main analysis, the health conditions were analyzed using a method called a Cox proportional hazards model.(4) This Cox model takes into account the fact that health conditions occur at different times after initial exposure. In this study, a worker is seen as contributing risk time only from the time of his first exposure until the time he experiences the health condition being analyzed.* In assessing the main effect of exposure on the rates of various health conditions, the Cox model controlled the influence of all major sociodemographic variables and other possible confounding variables (e.g., age, smoking habits and other exposure to chemicals).

The cumulative incidence rate of each health problem within the exposed and control group was based on the following ratio:

$$\frac{\text{the number of first episodes of the condition since first employment}}{\text{the number of person-years without, or prior to the condition, since first employment}}$$

The relative risk was derived from the exponent of the hazard function in the Cox model, which is an estimate of the instantaneous hazard rate which is assumed to be constant over time. It was related to:

$$\frac{\text{the cumulative incidence rate, given landfill site exposure}}{\text{the cumulative incidence rate, given no landfill exposure}}$$

The probability value (p) for the relative risk was based on the score from:

$$\frac{\text{partial coefficient (group/confounders)}}{\text{standard error of coefficient}}$$

The results of the main analysis were deemed positive if the probability value (p) for the relative risk was less than or equal to 0.05 (i.e., if the probability of the outcome occurring by chance alone was five in one hundred or less). Also used in the analysis of risk associated with gradient of exposure for landfill workers was a statistical parameter called the chi square (x^2) of the linear trend.

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* The risk time for exposed workers began with the year they were first exposed to the Upper Ottawa Street landfill. For those who worked there before 1965, 1965 was taken as the first year at risk. The risk time for the workers in the control group began with the first year of the job that qualified them for the control group, or 1965, if they began work before that year. Followup continued until the year of interview (i.e., 1983), whether or not the individual had left the job. To be included in the analysis, the specific medical conditions reported by the landfill workers had to have shown their first symptoms after the individual was exposed to the landfill or in the case of the control group, after the beginning of the analogous outdoor work. All events prior to 1965 were excluded.

When clusters of health conditions were analyzed, only the first eligible event within the cluster was counted. Workers who reported a first incidence of the condition prior to exposure did not contribute risk time to the analysis. Exposures to chemicals and other toxic agents throughout the respondents' working lives were included as potential confounders in the appropriate analyses. Many of those exposures occurred before 1965 or the beginning of the job which gained the respondent entry into the study. Chemical exposure and smoking status were the only elements of pre-exposure information included in the main analysis.

B4.3 Data Relating to Recall Bias

The data were analyzed in three ways:

Analysis 1. All self-reported events were included except those where the individual had reported seeing a physician but no evidence of the condition could be found on the physician's chart. In such cases, person-years were contributed up to, but not beyond, the date of the reported illness. All events reported by those refusing examination of their medical charts were included.

Analysis 2. All events which were neither confirmed nor possibly confirmed by medical chart abstraction were excluded. For this reason, information from those who refused access to their doctor's medical charts, those who did not see a physician, or those who saw a physician who was not contacted by the abstractors, was excluded.

Analysis 3. Only those events which were confirmed by medical chart abstraction were included.

These three analyses allowed the incorporation of data relating to recall bias into the main analysis. Analysis 1, because it included the largest number of events, was the most statistically powerful, but also the most subject to bias. Conversely, Analysis 3 was the least powerful statistically, but also the least subject to bias.

B4.4 Subanalyses

In addition to the main analysis, subanalyses were carried out to answer a number of specific questions: 1) did the onset of health problems cluster during the peak dumping periods at the landfill site; 2) when the conditions occurred in relation to the first exposure to the landfill site; 3) whether or not the risk of higher incidences of conditions differed among those who worked directly on the site, adjacent to the site, and in the control group; 4) if symptoms clustered in unique complexes; and 5) whether or not differences in health between landfill workers and controls that began after first exposure still persist. Information on current health was compared with information from the Canada Health Survey to see whether or not consistent results would have been found had the Survey questions alone been used. Detailed analysis of the data abstracted from the respondents' medical charts was conducted to assess recall bias. Reproductive outcomes, work-related injuries, and mortality among exposed workers were also analyzed.

C. RESULTS

C1. DESCRIPTIVE STATISTICS

C1.1 Rates of Response

It was possible to complete interviews for 84.5 per cent of the group exposed to the landfill site, but for only 71.9 per cent of the controls, probably because the controls had no direct interest in the outcome of the study. While most of the refusals were ostensibly for reasons unrelated to health, it is possible that the difference in refusal rates reflects a health-related volunteer bias.

A high percentage of both landfill workers annd controls consented to the examination of their medical charts (86.3 per cent of eligible exposed workers and 83.8 per cent of controls). At least one usable chart was abstracted for 92.5 per cent of exposed workers and 91.5 per cent of controls who consented.

C1.2 Comparability of Groups

Analyses of the comparability of the exposed workers and controls yielded the following information.

C1.2(a) Age Distribution. The mean age of the exposed workers was 49 years; the mean age of the control group was 47.4 years. There were proportionally more younger and older workers among the control group, and more middle-aged workers among the exposed. Consequently, there were statistically significant overall differences in age distribution. All health outcomes were, therefore, adjusted for age, whether or not they were age-dependent.

C1.2(b) Selected Sociodemographic Variables. There were no appreciable differences between the groups in terms of ethnic origin or home ownership. Compared to the control group, in which more workers were single, separated, or divorced, the group of exposed workers contained a higher proportion of individuals who were married or living common law. This reflected the increased proportion of younger workers among the controls. Relatively few respondents lived in homes with asbestos or UFFI insulation, but a greater proportion in the control group got their drinking water from wells, undoubtedly because some controls lived in the rural municipalities. The difference, if any, between the risks of drinking well water and Hamilton drinking water are unknown. In any case, neither of these variables has been seriously connected with the health problems of interest to this study.

C1.2(c) Education Status. Educational levels did not differ significantly between groups. A tendency towards a higher level of education among the exposed workers was not confirmed by statistical analysis for linear trend.

C1.2(d) Family Income. A statistically significant trend towards higher income among the exposed workers reflects the inclusion of some employees who had been promoted to professional jobs and of some senior officers among the firefighters in this group. The modal income range was the same for both groups. The income patterns seen in the study groups give little cause for concern regarding the comparability of landfill workers and controls in terms of income.

C1.2(e) Drinking Habits. The drinking habits of the two groups were very similar. The proportions of daily drinkers and total abstainers were almost identical; some variation was found among those who drank a few times per week to monthly or less. The potential impact of these differences on the health of the subjects should be negligible.

C1.2(f) Smoking Habits. There were no statistically significant differences between the groups in past and current smoking habits. There were non-statistically significant trends among the exposed workers towards smoking more and starting younger, and appropriate statistical adjustments were made in the analysis of respiratory conditions because of this trend.

C1.2(g) Exposure to Toxic Substances. The respondents were asked to report exposures to toxic substances in jobs other than those at the landfill site since the beginning of their working lives. Because the controls were able to report all exposures while, for this question, the exposed workers could report only those that occurred before or after employment at the landfill site, there were large differences in reported exposure to petroleum products, solvents, fertilizers, pesticides, paints, and plastics. In fact, the effect of adjustment for exposure to non-landfill toxics was minimal in the main analyses.

C2. MAIN ANALYSIS

From the complete list of 120 complaints in the questionnaire, there were 13 individual health conditions and groups of biologically related complaints where there was a 50 per cent or greater difference in the incidence (not adjusted for age or follow-up time) between exposed workers and controls and at least 15 eligible events in total. In all cases the cumulative incidence among the exposed workers turned out to be greater than that among the controls. None of the health complaints included in the questionnaire were found to occur more frequently in controls that in the landfill workers.

The data were analyzed in three phases described earlier (see page 219) and a summary of the results of these analyses is shown in Table 36.

Table 36: **The Risk of Developing Health Conditions Associated with Working At or Near the Upper Ottawa Street Landfill Site**

Health Conditions(1) (confounders (a-i) used in the model)(2)	Relative(3) Risk	Analysis 1(6)			Relative Risk	Analysis 2(7)			Relative Risk	Analysis 3(8)		
		p(4)	n of events(5)			p	n of events			p	n of events	
			landfill workers	controls			landfill workers	controls			landfill workers	controls
chronic bronchitis (a,b,c,d)	3.52	.015	12	4	4.18	.015	10	3	6.49	.008	10	2
difficulty breathing (a,b,c,d)	1.45	.143	19	15	2.12	.038	16	9	1.58	.167	11	8
daily cough (a,b,c,d)	2.38	.006	22	14	3.29	.005	16	7	2.83	.030	10	5
combined bronchitis emphysema, difficulty breathing, daily cough (a,b,c,d)	1.81	.008	40	30	2.57	.0009	32	17	2.31	.006	25	15
skin rash (d,e,g,h)	1.40	.204	14	12	1.73	.125	12	8	1.60	.166	11	8
combined skin rash, acne, discoloured patches on skin (d,e,g,h)	1.83	.024	27	21	1.83	.057	17	13	1.83	.057	17	13
Cardiac- angina, heart attack (a,b)	2.19	.016	20	12	1.76	.077	15	10	1.70	.115	12	9
arthritis/ rheumatism (a,b,c)	1.59	.043	32	26	1.93	.019	25	17	1.83	.057	22	16
red,itchy eyes (d,e,g)	1.63	.130	13	10	4.14	.021	8	3	NA(9)	NA	NA	NA
Mood Symptoms anxiety, depression, trouble sleeping, irritability, restlessness (a,e,f,g,i)	4.70	.0001	29	11	3.58	.003	17	8	4.72	.0001	15	6
Central Nervous System Symptoms headaches,dizziness, lethargy, balance problems (a,e,f,g,i)	2.45	.005	25	14	2.49	.014	19	10	4.72	.005	17	5
tremors, cramps, spasms (a,e,f,g,i)	2.23	.078	13	6	NA(9)	NA	NA	NA	NA	NA	NA	NA
muscle weakness (legs & arms) (a,e,f,g,i)	2.58	.015	16	9	2.89	.022	11	6	1.64	.240	5	4

Notes:

(1) The 13 health conditions listed here are the only ones from the 120 in the questionnaire where a higher incidence was observed fc landfill workers than controls, and for which there are enough events to be analyzed statistically.

(2) The Cox proportional hazards model used a different combination of the following confounding variables for analyzing each of the 13 health conditions:

a = age (stratified by age at onset of entry into study group: 0-29, 30-49, 50+)
b = smoking status
c = non-landfill site exposure to dust
d = non-landfill site exposure to fumes and gases
e = non-landfill site exposure to solvents
f = non-landfill site exposure to pesticides
g = non-landfill site exposure to plastics
h = non-landfill site exposure to petroleum products
i = alcohol intake

(3) The association with landfill exposure gets stronger as the numerical value of the relative risk gets larger. For example, a relative risk of 3.00 means that the landfill workers were three times more likely than the controls to develop the health condition.

(4) 'p' is the probability value. It is a measure of statistical significance that shows the likelihood that an event occurred by chance rather than for the the reason being investigated. For example, a 'p' value of .05 in this table means that the likelihood of an increased relative risk occurring by chance is only five per cent.

(5) 'N of events' is the number of landfill workers and controls who reported having the health condition.

(6) Analysis 1 is the most statistically powerful but also the most subject to bias because it includes all self-reported health problems except for those for which no evidence could be found in the chart abstraction.

(7) Analysis 2 excludes all events which were not confirmed or possibly confirmed by chart abstraction.

(8) Analysis 3 is the least statistically powerful but also least subject to bias because the only events included are those which were confirmed by chart abstraction.

(9) NA means Not Analyzed because too few of the landfill workers and controls who reported having problems with tremors, cramps, spasms saw a physician about these problems and, therefore, there were too few of these events to be analyzed.

The following relationships were observed:

1) There was a strong and consistent association between reports of chronic bronchitis, daily cough, and combined respiratory complaints and exposure to the site, whether or not unconfirmed reports were excluded. No similar differences between the groups were noted for other respiratory problems such as asthma or pneumonia.

2) An association between exposure to the landfill site and skin problems (i.e., skin rash, unusual acne, or new, discoloured skin patches) was identified, whether or not unconfirmed reports were excluded. This association was much weaker than that found for the respiratory group and was influenced by the choice of confounders.

3) Strong and consistent associations were found between mood symptoms (i.e., anxiety, depression, trouble sleeping, irritability, and restlessness) and central nervous system symptoms (i.e., headaches, dizziness, lethargy, balance problems), and exposure to the landfill site, whether or not these complaints were confirmed in the respondents' medical charts.

4) The analysis of the association between irritant symptoms and neuromuscular symptoms and exposure to the landfill site was limited as a result of the relatively small proportion of these symptoms reported to a physician or confirmed by examination of the medical charts.

5) A consistent, though biologically unexplained, association between arthritis and exposure to the landfill site was identified, whether or not the complaint was confirmed in the respondents' medical charts. It should be noted that the relative risk did not exceed 2.00.

6) An association of angina and heart attack with exposure to the landfill site was seen in Analysis 1, but the association lost its statistical significance when only events confirmed in the medical charts were considered in Analysis 3.

In general, the conditions eligible for analysis fell within the anticipated range of potentially environmentally-related complaints, with the exception of arthritis/rheumatism and cardiac conditions. No association was found between landfill site exposure and several major chronic health problems which are not thought to be related to toxic chemicals (i.e., high blood pressure, stroke, diabetes, gall bladder disease, and stomach ulcer). No associations were seen between landfill site exposure and any gastrointestinal, kidney, and bladder conditions or diseases of the blood, which might be associated with chemical exposures.

C3. SUBANALYSES

C3.1 Time Clustering

The first subanalysis was designed to determine if the onset of the 13 conditions identified in the main analysis coincided with the period when the largest volumes of waste were being disposed of at the landfill. If this were the case, intensity of exposure would correspond with concurrent risk. A descriptive analysis of the data was conducted to identify the conditions whose maximum risk of first onset occurred during the periods of greatest environmental risk, either 1970-75 (i.e., the period of rapidly increasing volume of disposal) or 1976-80 (i.e., the period of maximum disposal). Cumulative incidence rates for each condition were calculated for each time period. The denominator included the person-years of exposure within the time period of interest and excluded the person-years of exposure of those who had reported onset of symptoms in a previous time period. Tests of statistical significance were not included because of the small number of events in each time period. Table 37 shows the periods of time during which landfill workers were most likely to have first developed any of the 13 identified health conditions.

The following conclusions can be reached about the findings presented in Table 37.

1) The conditions tend to cluster between 1970-75 and 1976-80, especially the former, which suggest that the onset of health problems in landfill workers coincides with the periods of growing and maximum waste disposal at the landfill.

2) Two conditions cluster in the 1981-1983 period: red, itchy eyes and tremors, cramps, and spasms. Concurrent exposure would likely be required if exposure to the landfill were to have caused red, itchy eyes, so the credibility of this association is reduced. The possibility of a latent effect on the development of tremors cannot be excluded.

3) The combined respiratory and combined skin groups cluster in the 1965-69 period, despite the fact that the conditions contributing to both groups (i.e., chronic bronchitis, difficulty breathing, daily cough, and skin rash) cluster in the 1970-75 period. This is a statistical artifact based on counting the first event within each group and does not reduce the credibility of these associations.

C3.2 Risk Gradient with Duration of Exposure and Time since First Exposure

The data were analyzed to identify the period of greatest risk since first exposure to the landfill site, for each of the 13 conditions using Analysis 1 data (see page 219). Three time periods since first exposure, 0-5 years, 6-10 years, and 11-18 years, were chosen. The person-years of exposure used to calculate rates of incidence of each condition were those within each period and no age adjustments were made.

Table 37: **The Years of Highest Risk (for Landfill Workers as Compared to Controls) For Developing Health Conditions (in Terms of Events per 1,000 Person Years)**

Health Condition	Period[1]	Relative Risk[2]
Combined respiratory	1965-69	3.65
Combined skin	1965-69	5.05
Chronic bronchitis	1970-75	Inf [3]
Difficulty breathing	1970-75	3.32
Daily cough	1970-75	3.30
Combined cardiac	1970-75	2.54
Skin rash	1970-75	Inf [3]
Arthritis/rheumatism	1970-75	2.28
Mood symptoms	1976-80	9.41
Central nervous system symptoms	1976-80	8.53
Muscle weakness (arms & legs)	1976-80	2.99
Red, itchy eyes	1981-83	2.27
Tremors, cramps, spasms	1981-83	9.19

Notes:

[1] This is the period of time during which the landfill workers were most likely to report the beginning (i.e., onset) of the health condition.

[2] In this table, the association of a specific period of time with the onset of a health condition for landfill workers gets stronger as the relative risk gets larger.

[3] A relative risk of "Inf" (infinity) indicates that there were some events in the exposed group but none in the controls. Before this was accepted as indicating the period of highest relative risk, it had to meet the criterion of at least five events in the exposed group. If there were fewer than five events, the period was not considered and instead the period of highest relative risk in which there were at least some events in both groups is indicated in the table.

Table 38 shows that these conditions tended to appear in landfill workers during the first five years after initial exposure. This implies that if landfill site exposure were the cause of the health problems, these conditions did not require long-term cumulative exposure. This is consistent with the health conditions that were reported.

C3.3 Risk Associated with Onsite Exposure Versus Exposure Adjacent to the Landfill

As noted above, the exposed workers include some who worked directly on the landfill site and others who worked at the city works yard or at a training station beside the site (see Figure 2). In the absence of valid data on individual exposure, this distinction was the best available index of intensity of exposure. Table 39 shows the gradient of risk associated with onsite exposure, exposure adjacent to the landfill, and non-exposure by the controls.

Strong evidence of linear trend (i.e., a large and continuing increase in incidence as one moves from controls to adjacent and onsite landfill workers) is demonstrated for chronic bronchitis, daily cough, mood and narcotic symptoms, muscle weakness in arms and legs, and the combined respiratory group. Evidence of an increase in the incidence rate of the combined skin variable is also evident, but it achieved only borderline statistical significance.

C3.4 Correlations between Health Conditions.

The health conditions of interest in this study involve different organ systems. If the same groups of health problems tended to occur in common in exposed individuals to a greater extent than in controls, this would be evidence of a 'landfill site syndrome'. Analysis showed that the overall tendency was for higher correlations between symptoms among the controls than the exposed workers. There is no evidence, therefore, of a landfill site syndrome as defined by this type of analysis.

C3.5 Differences in Health Status at Time of Interview

At the time of interview, study respondents were asked whether or not they still had each of the health conditions they reported. Using this information, the 13 health conditions of interest were re-analyzed for differences in current prevalence between landfill workers and controls. Those events that were included in Analysis 1 in the main analysis (Table 36) were followed forward in time and included if the respondents said they still had the condition at the time of interview. This was done to answer the question: are the health status differences that emerged after first exposure to the landfill reflected in the current prevalence of the conditions of interest?

Table 38: **The Period of Highest Risk (for Landfill Workers as Compared to Controls) by Number of Years since First Exposure**

Health Condition	Years Since First Exposure[1]	Relative Risk[2]
Chronic bronchitis	0-5	3.42
Difficulty breathing	0-5	3.85
Combined respiratory	0-5	2.03
Skin rash	0-5	1.92
Combined skin	0-5	4.85
Arthritis/rheumatism	0-5	2.06
Central nervous system symptoms	0-5	3.59
Mood symptoms	0-5	5.11
Muscle weakness (arms & legs)	0-5	6.61
Daily cough	6-10	3.31
Combined cardiac	6-10	3.89
Red, itchy eyes	6-10	6.73
Tremors, cramps, spasms	6-10	6.69

Notes:

[1] This is the number of years after first being exposed to the site that landfill workers were most likely to have developed the health condition.

[2] In this table, the association of the timing of first exposure to the landfill with the onset of the health condition in workers gets stronger as the relative risk gets larger.

Table 39: The Risk Associated with Gradient of Exposure for Persons Who Worked Onsite, and Adjacent to the Landfill, and for Controls

Health Condition	Exposure(1) Groups	Incidence(2) %	(n)	x^2lin(3)	p(4)
Chronic bronchitis	Onsite	13.3	(8)	8.44	.004
	Adjacent	5.3	(4)		
	Controls	2.7	(4)		
Difficulty breathing	Onsite	17.5	(11)	2.50	.114
	Adjacent	10.1	(8)		
	Controls	9.3	(15)		
Daily cough	Onsite	23.0	(14)	6.75	.009
	Adjacent	10.8	(8)		
	Controls	9.0	(14)		
Combined respiratory	Onsite	34.3	(23)	6.28	.012
	Adjacent	21.3	(17)		
	Controls	18.3	(30)		
Cardiac	Onsite	11.9	(8)	1.85	.173
	Adjacent	15.2	(12)		
	Controls	7.4	(12)		
Skin rash	Onsite	12.1	(8)	.98	.323
	Adjacent	7.8	(6)		
	Controls	7.6	(12)		
Combined skin rash, unusual acne, discolored patches on skin	Onsite	22.4	(15)	3.07	.080
	Adjacent	15.0	(12)		
	Controls	12.8	(21)		
Red, itchy eyes	Onsite	12.5	(8)	2.07	.150
	Adjacent	6.4	(5)		
	Controls	6.3	(10)		
Arthritis/rheumatism	Onsite	15.9	(10)	.13	.715
	Adjacent	29.7	(22)		
	Controls	17.0	(26)		
Mood symptoms	Onsite	22.4	(15)	7.87	.005
	Adjacent	12.5	(10)		
	Controls	8.5	(14)		
Central nervous system symptoms	Onsite	26.9	(18)	16.86	∠ .0001
	Adjacent	13.8	(11)		
	Controls	6.7	(11)		
Tremors, cramps, spasms	Onsite	9.1	(6)	3.04	.081
	Adjacent	9.0	(7)		
	Controls	3.7	(6)		
Muscle weakness (arms & legs)	Onsite	16.4	(11)	6.47	.011
	Adjacent	6.3	(5)		
	Controls	5.5	(9)		

Notes:

1 The onsite exposure group consisted of persons who worked directly on top of the landfill such as salvage pickers, scalemen, security guards, heavy equipment operators, waste testers, solidification plant attendants and supervisors.
The adjacent exposure group consisted of persons who worked beside the landfill site such as firefighter instructors, garbage men, and city works yard employees. The controls have had no known exposure to a landfill site or regular exposure to herbicides and pesticides.

2 The incidence of the health condition in each of the three exposure groups is shown as a percentage and (n) is the number of persons who reported having the health condition.

3 'x^2lin' is a chi square for linear trend. It is a statistical parameter used here to determine if the risk of developing the health condition for onsite landfill workers was higher than the risk for workers adjacent to the landfill and whether the latter was higher than the risk for controls. The existence of linear trend would strengthen the association between landfill exposure and illness in landfill workers.

4 'p' is the probability value and in this table it measures whether the linear trends occurred by chance. A 'p' value of less than 0.05 would indicate that the linear trends are statistically significant.

Table 40 shows that for all conditions except red, itchy eyes, the odds ratio* is greater than its respective relative risk from Table 36. This means that the prevalence of the health conditions is greater among landfill workers than controls. At the same time , all probability values (p) have increased. The proportional decrease in the number of controls reporting still having the condition was greater than in the number of exposed workers for all conditions except chronic bronchitis and tremors, cramps and spasms in which the proportional decrease is equal between exposed workers and controls.

The differences in odds ratios and probability values (p) from Table 36 to Table 40 are related both to differing statistical methods and the differences between incidence and prevalence of the conditions of interest. In general, the proportional decrease between analyses are not strikingly greater among acute than chronic conditions. Chronic bronchitis and cardiac symptoms show greater proportional decreases than red, itchy eyes or skin rash. However, proportional decreases in difficulty breathing and arthritis/rheumatism are predictably low. These results reflect a variety of influences: time from condition onset to the present (Table 37), subject to interpretation of what "still having a condition" means, the validity of the original self-report, the nature and severity of the underlying pathology involved, and the presence or absence of ongoing exposure to causative factors. The effects of these factors cannot be estimated separately using the data in this study.

The data show that while the health problems appear to be disappearing among landfill workers and controls, the rate of decrease is slower among landfill workers. Therefore, the health status differences that emerged after first exposure to the landfill still exist, although to a lesser extent.

C3.6 Other Health Problems

The experience of the landfill workers and controls with respect to work-related injuries is similar, with approximately 75 per cent of both groups reporting at least one such injury. A similarly high proportion of each group (68 per cent of landfill workers and 59.8 per cent of controls) received Worker's Compensation payments at least once. There is no evidence of claims for chemical-related disease from exposure at the landfill.

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* The odds ratio is analogous to relative risk but in analyses such as these where differences in number of events and not incidence rates are being examined, it is a more valid statistical parameter. The odds ratio is based on the ratio of:

$$\frac{\text{the odds in favour of getting disease if exposed}}{\text{the odds in favour of getting disease if not exposed}}$$

Table 40: **Relative Prevalence of Selected Health Conditions at Time of Interview**

				Table 36 - Analysis 1		
Condition	n of events[1] (landfill workers, controls)	Odds Ratio[2] (landfill workers, controls)	p	n[3]	Relative[4] Risk	p
Chronic bronchitis	(6,2)	3.80	.091	(12,4)	3.52	.015
Difficulty breathing	(18,12)	1.50	.321	(19,15)	1.45	.143
Daily cough	(18,7)	3.22	.020	(22,14)	2.38	.006
Combined respiratory	(32,20)	2.80	.047	(40,30)	1.81	.008
Skin rash	(12,6)	1.83	.233	(14,12)	1.40	.204
Combined skin	(20,9)	2.30	.076	(27,21)	1.83	.024
Cardiac	(14,7)	2.96	.005	(20,12)	2.19	.016
Arthritis/rheumatism	(30,19)	1.95	.049	(32,16)	1.59	.043
Red, itchy eyes	(10,6)	1.49	.354	(13,10)	1.63	.130
Mood symptoms	(27,6)	5.09	.0015	(29,11)	4.70	< .0001
Central nervous system symptoms	(23,9)	2.72	.026	(25,14)	2.45	.005
Tremors, cramps, spasms	(13,6)	2.49	.083	(13,6)	2.23	.078
Muscle weakness (arms & legs)	(16,5)	3.61	.016	(16,9)	2.58	.015

Notes:

[1] Number of health conditions landfill workers and controls reported still having at time of interview.

[2] Odds ratio is a statistical parameter which is used in this table to show how much more likely it is for landfill workers still to have a higher prevalence of the health conditions compared to controls at time of interview.

[3] Number of health conditions reported by landfill workers and controls on questionnaire as developing before 1981.

[4] The relative risk that landfill workers were more likely to develop the health conditions than the controls before 1981.

No statistically significant differences between the groups are found in the one-year infertility rate, the spontaneous abortion rate, stillbirths among the pregnancies beginning after first exposure of the father at the landfill, or birth defects.

C3.7 Mortality

A total of 21 exposed workers were reported to have died between 1965 and the end of 1983. Twenty of these deaths were verified in the Ontario Death Registry and analyzed using proportional mortality ratios (PMR)* and standardized mortality ratios (SMR).**

Neither analysis demonstrated an elevated risk of death among workers exposed to the landfill, although the PMR showed a trend toward increased respiratory diseases (both cancer and non-cancer). The overall pattern of mortality was consistent with that of many working populations. Because of the low power of these analyses, it cannot be concluded that exposure to the landfill site had by 1983 affected in any significant way the risk of mortality for exposed landfill workers.

C3.8 Comparisons Using Canada Health Survey Questions

Questions from the Canada Health Survey concerning long-term health problems were included in the questionnaire developed for this study to see if the use of CHS data in place of data obtained from a locally selected matched control group would have given similar results. Because the CHS questions differed from those in the rest of the questionnaire in several respects, comparisons were made separately between the exposed workers, the controls, and all male CHS blue collar workers and were adjusted for age. The exposed workers differed from the CHS sample in all items, with high levels of statistical significance in 14 of 18 items. These differences did not show up in the main analysis, which used the part of the questionnaire developed for this study. The trend for the controls was similar, although less marked: the odds ratio was greater than one in 16 of 18 items and less than one in two items; seven items achieved high levels of statistical significance, six of which related to an increased prevalence among the controls. It is clear that a locally selected control group was necessary for this study and that a huge bias would have been introduced if CHS data had been used as a benchmark comparison.

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* The PMR is the ratio of the proportion of deaths from a particular cause in landfill workers to the proportion of deaths from that cause in all Ontario males.

** The SMR is the ratio of the observed number of deaths of landfill workers to the number of deaths expected in this group based on the mortality experience of all Ontario males.

C3.9 Quality of Self-Reported Health Histories

In an effort to eliminate recall bias, the main analysis included information abstracted from respondents' medical charts to give results for confirmed health events. In general, recall bias did not influence that analysis to a significant degree. Further analysis of the information from the medical charts showed that over-reporting was low in both the exposed workers and the controls and that respondents' knowledge of exposure to toxic chemicals did not result in more visits to a physician.

Almost 72 per cent of all conditions reported were confirmed when a visit to a physician was reported. When possible confirmations were included, 88.9 percent were confirmed. Confirmation from medical charts was also made on 36.5 per cent of the respondents' reports when no visit to a physician had been reported, and a further 22.6 per cent of such 'non-reports' were possibly confirmed.

It was anticipated that rates of non-confirmation would increase with increasing time since the event. Instead, non-confirmation was lowest for conditions beginning before 1965 and highest for conditions beginning in 1981 or thereafter. This may have been due to increased respondent recall of minor health problems in the recent past compared to the distant past. Excluding the pre-1965 period, differences in confirmation rates for conditions beginning 1965-69, 1970-80, and 1981-83 were quite small.

Differences between the groups in the distribution of confirmed, possibly confirmed, and unconfirmed events were not evident either before (up to 1977) or after (1978-83) the beginning of intense public concern about the landfill. The proportion of unconfirmed events, however, rose 9.9 per cent in the landfill workers group and 4.8 per cent in the controls after the onset of publicity.

Table 41 presents the medical chart abstraction data by condition for landfill workers and controls. The chart abstraction results for the 13 conditions of interest produced no evidence of increased over-reporting among exposed workers. In fact, narcotic symptoms were relatively over-reported among the controls.

Comparison of the percentages of exposed workers and controls who reported seeing a physician if they had a condition in a specific organ system revealed no evidence of an increased rate of visits to a physician for the exposed workers compared to the controls. In general, the trend was toward increased visits among controls.

D. CONCLUSIONS

The credibility of the associations between exposure to the landfill site and the 13 health conditions in the main analysis was evaluated by criteria which were specified before the data were analyzed. These were biological plausibility, statistical strength, lack of evidence of recall bias, time cluster, risk gradient by intensity of exposure, and an overall credibility rating. A summary of the

Table 41: A Comparison of Medical Chart Abstraction Results For Over-Reporting by Selected Health Conditions

Health Condition	Confirmed[1]	Possibly Confirmed[2]	Not Confirmed[3]	p[4]
Chronic Bronchitis				
Landfill Workers	16	1	-	
Controls	10	2	-	.348
Difficulty Breathing				
Landfill Workers	12	4	-	
Controls	8	2	-	.768
Daily Cough				
Landfill Workers	13	3	-	
Controls	7	1	-	.593
Combined Respiratory				
Landfill Workers	45	8	-	
Controls	26	6	-	.659
Skin Rash				
Landfill Workers	10	1	2	
Controls	7	0	0	.282
Combined skin rash, unusual acne, discoloured patches on skin				
Landfill Workers	17	3	6	
Controls	14	0	2	.158
Angina/Heart Attack				
Landfill Workers	17	4	-	
Controls	15	3	-	.847
Arthritis/rheumatism				
Landfill Workers	22	4	2	
Controls	18	1	0	.215
Red, itchy eyes				
Landfill Workers	3	3	3	
Controls	4	1	1	.315
Mood Symptoms				
Landfill Workers	15	3	1	
Controls	5	1	2	.633
Central nervous system symptoms				
Landfill Workers	26	2	3	
Controls	8	6	1	.036[7]
Tremors, cramps, spasms				
Landfill Workers	3	2	2	
Controls	3	0	1	.545
Muscle weakness (arms & legs)				
Landfill Workers	4	8	-	
Controls	4	4	.556	.456

Notes:

1 'Confirmed' refers to the number of health conditions reported in the questionnaire (by landfill workers as compared to controls) that were verified by chart abstraction.

2 'Possibly confirmed' refers to the number of health conditions reported in the questionnaire (by landfill workers as compared to controls) that were verified as such by chart abstraction.

3 'Not confirmed' refers to the number of health conditions reported in the questionnaire (by landfill workers as compared to controls) that could not be verified by chart abstraction.

4 'p' is the probability value. In this table it refers to the likelihood that the proportions of health conditions (for landfill workers as compared to controls) shown to be confirmed, possibly confirmed, or not confirmed by chart abstraction occurred by chance. The high p values indicate an absence of statistical significance and, therefore, no over-reporting by landfill workers.

5 Central nervous system symptoms were over-reported by the controls.

results of the evaluation of each of the 13 health conditions by each of these criteria is presented in Table 42.

The associations that are most credible and, therefore, most likely to represent a causal relationship, are with chronic bronchitis, daily cough, combined respiratory problems, central nervous system symptoms, and mood disorders. The associations with difficulty breathing, skin rash, combined skin problems, and muscle weakness are moderately credible. The level of credibility of the associations with cardiac disorders, arthritis, red, itchy eyes, and tremors, cramps, and spasms are low.

The results of this study cannot be used independently to draw conclusions about causation. For the reasons set out on page 212 the study was intended to be an hypothesis-generating study. On the other hand, hypothesis generating and hypothesis testing are related activities on a scale of probability. An epidemiologic study like this one may be viewed as a diagnostic test, in which the probability that the exposure to the landfill caused health problems for workers is greater now than it was before the study was conducted because some positive results were obtained.

The health conditions ranked as highly credible hypotheses are more likely to have been caused by exposure to the landfill site than those ranked moderate or low. But the unavoidable methodological limitations of this study dictate that none of these hypotheses has achieved a level of credibility such that a scientific consensus would conclude landfill exposure has caused the increased incidence of health problems observed in the exposed workers.

The health problems identified in the workers study were intended to provide hypotheses to be tested in the residents study. It was postulated that the effect of landfill exposure on workers and residents should be similar. The residents' study was designed to determine as definitively as possible whether or not this is the case. Similar results from the two studies would strengthen the evidence that landfill exposure was the cause of the health problems in question. (See page 286).

Table 42: An Evaluation of the Association of Specific Health Problems and Working at or Near the Upper Ottawa Street Landfill

Health Condition[1]	Is there Biological Plausibility?[2]	Strength of Association		Is there Evidence of Recall Bias?[5]	Is there Time Clustering in (1970-75) or (1976-80)?[6]	Does a Risk Gradient by Intensity of Exposure Exist?[7]	What is the Overall Credibility of the Association?[8]
		Is the Relative Risk more than 2.0?[3]	Is the value of p less than 0.05?[4]				
Chronic Bronchitis	yes	yes	yes	no	yes	yes	High
Difficulty Breathing	yes	no	no	no	yes	yes	Moderate
Daily Cough	yes	yes	yes	no	yes	yes	High
Combined Respiratory	yes	yes	yes	no	NA	yes	High
Combined Cardiac	yes	no	no	no	yes	no	Low
Skin Rash	yes	no	no	no	yes	yes	Moderate
Combined Skin	yes	no	no	no	NA	yes	Moderate
Red, Itchy eyes	yes	NA[9]	NA	no	no	yes	Low
Arthritis	no	no	no	no	yes	no	Low
Central Nervous System Symptoms	yes	yes	yes	no	yes	yes	High
Mood Disorders	yes	yes	yes	no	yes	yes	High
Tremors, cramps, spasms	yes	NA	NA	no	no	no	Low
Muscle Weakness (arms & legs)	yes	no	no	no	yes	yes	Moderate

Notes:

1. The 13 health conditions listed here are the only ones from the 120 in the questionnaire where a higher incidence was observed for landfill workers than controls and for which there were enough events to be analyzed statistically.

2. Biological plausibility is used to show whether the literature on the health effects associated with chemical exposure provides evidence that the 13 health conditions could be caused by exposure to toxic chemicals in the landfill.

3. The relative risk criteria requires that landfill workers be at least twice as likely as controls to develop the health problem. These data are shown in Analysis 3 of Table 36.

4. The probability of an increased relative risk occurring by chance cannot exceed five chances in 100 in order to meet the criterion of a probability value (p) of less than 0.05. These data are shown in Analysis 3 of Table 36.

5. The data shown in Table 41 were used to determine if landfill workers over-reported health conditions as compared to controls.

6. The data presented in Table 37 were used to determine if landfill workers developed the health conditions during the years of high volume waste disposal at the site.

7. The data shown in Table 39 provide evidence of linear trend for chronic bronchitis, daily cough, combined respiratory, narcotic symptoms, mood disorders, and muscle weakness in arms and legs. Evidence of a non-linear trend was shown for difficulty breathing, skin rash, combined skin, and red, itchy eyes.

8. Overall credibility is derived from the combined 'scores' obtained from the criteria described above.

9. NA = Not Analyzed.

References

1. C. Hertzman, M. Hayes, J. Singer, and J. Highland, Report of the Workers' Health Study of the Upper Ottawa Street Landfill Site Study, 1985

2. Based on a questionnaire designed by the Love Canal Homeowners Association.

3. Environ Corporation, Preliminary Summary of the Inherent Toxic Properties of Selected Substances Tentatively Identified at the Upper Ottawa Street Landfill. January - February, 1983.

4. Cox, D.R. Progression Models and Life Tables, Journal of the Royal Statistical Society. Series B; 34: 187-220, 1972.

CHAPTER 12

SURVEY OF THE HEALTH OF PERSONS LIVING NEAR THE UPPER OTTAWA STREET LANDFILL

Table of Contents

Page

A. INTRODUCTION 244

B. MATERIALS AND METHODS 245

B1. IDENTIFICATION OF THE STUDY POPULATION 245

B1.1 Landfill Area Residents 245
B1.2 Controls 248

B2. DEVELOPMENT AND ADMINISTRATION OF THE QUESTIONNAIRE 249

B2.1 Design and Content of the Questionnaire 249
B2.2 Administration of the Questionnaire 250

B3. ANALYSIS OF THE DATA 251

B3.1 Objectives 251

B3.2 Was There an Increased Risk for Landfill Area Residents of Developing Health Problems? 252

B3.3 Was There an Increased Risk for Landfill Area Residents by Proximity to the Landfill or Duration of Residence? 253

B3.4 Was a Migrator Bias Caused by Residents Who Moved Away from the Landfill Neighbourhood? 253

B3.5 Are People Who Decide to Live Near the Landfill Less Healthy for Reasons that Are Unrelated to Landfill Exposures? 254

B3.6 Did the Increased Risk Among Landfill Area Residents Develop Before the Landfill Was Closed? 254

B3.7 Were Increased Risks Among Landfill Area Residents Also Found for Decoy Health Conditions? 254

B3.8 Did Landfill Area Residents Have an Increased Risk for Problems with Pregnancy or Birth Defects? 255

B3.9 Were There Any Other Health Problems for Which Landfill Area Residents Might Have an Increased Risk? 255

Page

B3.10 Was There Evidence of Over-Reporting or Under-Reporting Recall Bias from Medical Chart Abstractions? 255

B3.11 Are the Health Problems Found in Excess in Landfill Area Residents Likely to Continue? 256

C. RESULTS 257

C1. DESCRIPTIVE STATISTICS 257

C1.1 Rates of Response 257
C1.2 Comparability of Groups 257
C1.2(a) Sociodemographic Characteristics 257
C1.2(b) Drinking and Smoking Habits 258

C2. ANALYSIS OF THE DATA 258

C2.1 Was There an Increased Risk for Landfill Area Residents of Developing Health Problems? 258

C2.1(a) Health Problems Identified in the Workers Study 258
C2.1(b) Health Problems Identified from Other Sources 261

C2.2 Was There an Increased Risk for Landfill Area Residents by Proximity to the Landfill or Duration of Residence? 264

C2.3 Was a Migrator Bias Caused by Residents Who Moved Away from the Landfill Neighbourhood? 269

C2.4 Are People Who Decide to Live Near the Landfill Less Healthy for Reasons that Are Unrelated to Landfill Exposures? 273

C2.5 Did the Increased Risk Among Landfill Area Residents Develop Before the Landfill Was Closed? 273

C2.6 Were Increased Risks Among Landfill Area Residents Also Found for Decoy Health Conditions? 278

C2.7 Did Landfill Area Residents Have an Increased Risk for Problems with Pregnancy or Birth Defects? 279

Page

C2.8 Were There any Other Health Problems for Which Landfill Area Residents Might Have an Increased Risk? 280

C2.9 Was There Evidence of Over-Reporting or Under-Reporting Recall Bias from Medical Chart Abstractions? 280

C2.10 Are the Health Problems Found in Excess in Landfill Area Residents Likely to Continue? 281

D. DISCUSSION 286

References 292

Tables Page

43 Initial Classification of Households Adjacent to the Landfill Site 246

44 Risk of Developing Health Problems Associated with Living Near the Landfill Site for Adults 259

45 Risk of Developing Health Problems Associated with Living Near the Landfill Site for Children 262

46 Risk Gradient by General Proximity of Residence to Landfill Site: Short and Long-term Adult Residents 266

47 Risk Gradient by Continuous Distance Variable for Adults 267

48 Risk Gradient by General Proximity of Residence to Landfill Site: Long-term Adult Residents Only 268

49 Risk Gradient by General Proximity of Residence to Landfill Site: Short and Long-term Residents' Children 270

50 Risk Gradient by Continuous Distance Variable for Children 271

51 Risk Gradient by General Proximity of Residence to Landfill Site: Long-term Residents' Children Only 272

52 Analysis of Health Problems First Occurring Before 1981 for Adults 275

53 Migrator Effects: Relative Risks Before and After 1981 for Adult Non-Movers Versus Movers 276

Table		Page
54	Health Problems First Occurring After 1980, for Adult Recent Residents Versus Controls	277
55	Current Persistence and Prevalence of Groups of Health Problems in the Main Analysis for Adults	282
56	Current Persistence and Prevalence of Groups of Health Problems in the Main Analysis for Children	283
57	Current Persistence and Prevalence of Individual Health Problems for Adults	284
58	Current Persistence and Prevalence of Individual Health Problems for Children	285
59	Summary of the Results of Hypothesis Testing for Adults	288
60	Summary of the Results of Hypothesis Testing for Children	289

A. INTRODUCTION

This chapter describes the design and conduct of a health survey of current residents who live near the Upper Ottawa Street landfill site and former residents of the area.(1) The design of the study assumes that landfill residents may have been exposed to toxic industrial wastes deposited there, especially during 1976 to 1980 which available information identifies as the peak dumping period.

The objectives of the residents' health study were: (1) to determine whether the incidence rates of certain adult, child, and maternal-child health problems were greater among landfill residents than among a control population; (2) to assess the likelihood that living near the landfill caused health problems; (3) to assess whether or not such health problems would be likely to continue to affect the well-being of the residents after the landfill closed; and (4) to provide information concerning whether or not there is a need for medical follow-up.

The basic design of the residents study was very similar to the workers survey. It consisted of a health questionnaire that was administered to current and former landfill residents (who were divided into six study groups depending on the proximity of their house to the site and how long they lived there) and to two groups of controls living in a similar neighbourhood distant from the landfill site. The study also involved the abstraction of medical charts of landfill residents and controls.

The strategy behind the health study of landfill residents was to determine if health problems similar to those already found in landfill workers also occurred in residents. Such findings would strengthen the evidence of an association between ill health and exposure to the landfill. The problems identified in the workers study were: respiratory (chronic bronchitis, daily cough, difficulty with breathing), certain central nervous system disorders (headaches, dizziness, lethargy) and mood disorders (anxiety, depression, trouble sleeping), skin rash and muscle weakness. In addition, the residents study collected information on numerous other health conditions including those unique to children, problems with pregnancy and childbirth, and problems not known to be associated in any way with chemical exposures. The latter served as decoy questions.

The primary purpose of the analyses was to answer the crucial question: Is there a statistically valid association between living near the landfill site and increased rates of various health problems? It was recognized from the outset that it could be difficult to distinguish between two possible causes for any health problems found. First, they could have been caused by exposure to airborne chemical vapours, fumes, and particulate matter from the landfill or by direct skin exposure to landfill wastes as a result of recreational activities. Second, the anxiety caused by concern over the potential effects of exposure to the landfill could have given rise to genuine health problems or symptoms. This will be referred to as the 'perceptual' explanation of causation (i.e., perception of exposure by area residents to toxic chemicals).

B. MATERIALS AND METHODS

B1. IDENTIFICATION OF THE STUDY POPULATION

B1.1 Landfill Area Residents

Six groups of exposed households, which are shown in Table 43, were selected for the health survey:

1) those living within 500 metres of the edge of the dump face at the time of interview who had been resident there for 3 or more years between 1976 and 1980. Few, if any, households were located within 250 metres of the site. These long-term, exposed, current residents comprised the 1000 series.

2) those living within 500 metres of the edge of the dump face at the time of interview who had been resident there for less than 3 years between 1976 and 1980. These short-term, exposed, current residents comprised the 2000 series.

3) those living between 500 and 750 metres from the edge of the dump face at the time of interview who had been resident there for 3 or more years between 1976 and 1980. These long-term, exposed, current residents living farther away comprised the 3000 series.

4) those living between 500 and 750 metres from the edge of the dump face at the time of interview who had been resident there for less than 3 years between 1976 and 1980. These short-term, exposed, current residents living farther away comprised the 4000 series.

5) those living within 750 metres of the edge of the dump face at the time of interview who had not been resident there between 1976 and 1980. These recent residents who moved into the area after the lanfill closed comprised the 7000 series.

6) those who lived within 750 metres of the edge of the dump face sometime between 1976 and 1980 but subsequently moved out of the area. These movers or migrators who are former landfill residents comprised the 8000 series.

Table 43: **Initial Classification of Households Adjacent to the Landfill Site**

Current Residence	Distance from Landfill	Years of Exposure from 1976 to 1980	Number of Households	Series No.	Eligibility
Still There	within 500 metres	3 years	156	1000	Yes
		0 x 3 years	124	2000	Yes
		no exposure at that time	149	7000	Yes
(as of May, 1983)	500-750 metres	3 years	258	3000	Yes
		0 x 3 years	246	4000	Yes
		no exposure at that time	176	7000	Yes
Moved	within 500 metres	3 years	87	8000	Yes
		0 x 3 years	248	8000	Yes
		no exposure at that time	28	—	No
	500-750 metres	3 years	74	8000	Yes
		0 x 3 years	382	8000	*
		no exposure at that time	40	--	No

* Randomly-selected 50% of subgroup used in pre-test, 50% used in main study.

The considerations governing the choice of households, the size of the sample and the division of the eligible households into groups were:

1) period of exposure. Available information suggested that the landfill received the greatest volume of industrial waste from 1976 to 1980. The site was closed during 1980 and was capped late that year. Those who lived near the landfill during this period were further divided into those with fewer than three years exposure during 1976-80, and those with three or more years. This distinction made possible a three-point analysis of health problems according to duration of exposure: long-term residents, short-term residents, and controls.

2) distance of residence from the landfill. The decision to limit the landfill households chosen for the study to those within 750 metres of the site and to divide them into two groups according to distance from it, was based on practical considerations of sample size, ease of analysis and cost. Division of the 750 metre zone into two bands made it possible to plan three-point analyses by level of exposure: of households within 500 metres of the dump face, households between 500 and 750 metres from the dump face, and controls.

   Preliminary estimates from tax assessment rolls suggested that there were approximately 280 households within 500 metres of the dump face and 504 households from 500 to 750 metres, during the period of exposure (i.e., 1976-1980). Ultimately, a sample of 614 households still living near the site was identified. Assuming an 80 per cent response rate and 1.3 childbirths per household following first residence at the landfill, this sample size would allow 80 per cent power to detect a relative risk of 3.0 for all birth defects.

3) time of first exposure. Few households within 750 metres of the dump face between 1976 and 1980 were listed on the tax assessment roll before 1973. It was therefore assumed that virtually none of the eligible households had been established near the landfill before 1972, and 1972 was defined as the year of first exposure in the questionnaire and in the selection of controls.

4) identification and follow-up of the six groups of landfill households. Tax assessment rolls were consulted for 1983, 1980, and 1978 in order to determine which households were long and short term, current residents, recent residents or movers.

   Discrepancies between the initial tax assessment estimates and the number of actual households still living near the site (1000 to 4000 series) were small and were usually the result of double reporting of families on the rolls. Substantially fewer recent households (7000 series) actually existed than were estimated from tax assessments (325 estimated, 219 assigned), because the initial estimates had included many landowners who had not yet moved into the area or built there. Approximately two-thirds of the 600 households on the assessment rolls who had lived within 750 metres of the landfill site sometime between 1976 and 1980 and had moved away (8000 series), were found in Hamilton and surrounding municipalities through drivers license records and local telephone directories.

B1.2 Controls

The objective was to find a control community comparable to the landfill neighbourhood in family size, age distribution, and socioeconomic status. These factors would correlate closely with other health risk factors, both occupational and personal, that could confound the outcome of the study. It proved difficult to find such controls for two reasons. First, since the Upper Ottawa Street landfill neighbourhood was developed during the mid-1970s, the controls also had to be from newly developed communities. Secondly, the landfill neighbourhood was spread out over four census tracts and eight Hamilton Planning Department neighbourhoods. The proportion of population of each census tract within the study area, however, ranged from 20 to 75 per cent, while for planning neighbourhoods the range was from 0.5 to 34.0 per cent. Thus, existing data related to family size, occupation, and income were unhelpful in identifying a control community.

As an alternative approach, the size, type, building date, and resale value of houses were used as surrogates for family size, age, and socioeconomic status. Information provided by the Hamilton Planning Department helped to limit the search to neighbourhoods on the Hamilton Mountain, which were the only other communities of a similar age. These communities, situated on the Niagara Escarpment approximately eight km west of the landfill site, were in the same region for air pollution migrating south from Hamilton and north from the industrial belt in the U.S. Inspection of Planning Department and Real Estate Board records suggested that the Gilkson neighbourhood and part of the Fessenden neighbourhood would be the closest match that could be found. The selected Fessenden/Gilkson area contains a mixture of town houses and single, detached dwellings similar to those in the landfill area and resale values of houses were comparable.

The control households were divided into two subgroups: those who lived in the control area for less than three years between 1976 and 1980 (the 5000 series, whose duration of residence is comparable to that of landfill residents in the 2000 and 4000 series) and those who lived in the control area for three or more years between 1976 and 1980 (the 6000 series, whose duration of residence is comparable to that of landfill residents in the 1000 and 3000 series). Both groups were current residents at the time of the interview. There were too few control residents who moved in after 1980 to form a group comparable to recent landfill residents (7000 series). Similarly, migrators (like landfill residents in the 8000 series) were not sampled from the control community because of a very low rate of migration from the area. Overall, the control community had a higher proportion of long-term residents and was less migratory than the landfill site community.

B2. DEVELOPMENT AND ADMINISTRATION OF THE QUESTIONNAIRE

B2.1 Design and Content of the Questionnaire

Information was required about the health of every member of each household. Therefore, the questionnaire was designed to be answered by the female head of household, who is considered to be most knowledgable in reporting on behalf of the whole family.

The questionnaire used in the workers study, which had proved to be clear, easy to administer, and comprehensive, was used as a base to develop the questionnaire for the residents study. Its use of multiple descriptions of similar health problems in separate response categories had allowed the workers to find descriptions of illness that they could relate to their specific health conditions; the trade-off was that some health condition descriptions lacked medical exactness. A similar tradeoff was used in the residents study, especially in the sections on skin, and certain central nervous system and mood conditions.

Preliminary results of the analysis of the workers study had identified certain respiratory, skin, mood, and central nervous system conditions in excess in landfill workers as compared to controls. These conditions eventually emerged as the main hypotheses to be tested in the residents study, and corresponding sections in the residents' questionnaire were, therefore, strengthened. A 1978 survey conducted by the residents themselves was re-examined to ensure that all relevant aspects were included in the Committee's questionnaire.

The format for recording the responses for multiple members of a household and for multiple pregnancies was adapted from the Canada Health Survey. Questions regarding the current presence of chronic health problems were also adapted from the Canada Health Survey.

The sections of the questionnaire covering maternal and child health (pregnancy history, maternal risk factors, and outcome) were newly developed for the residents study since no validated questionnaires were available.

The questionnaire which was finally developed included questions on the following subjects:

a) identification of all current (or temporarily absent) household members
b) basic details about deceased household members and those who moved away before the interview
c) history of the family's (and the individual member's) residence in the landfill neighbourhood or control area
d) long-term health problems in each family member
e) each family member's smoking and drinking history
f) activities on land and recreation areas adjacent to the landfill

g) history of acute and chronic health problems from 1972 until the date of interview (including conditions not thought to be related to environmental exposure)
h) developmental history of those under the age of 16 at the time of interview
i) pregnancy history for all female respondents who had a pregnancy since 1968
j) history of school attendance and work within 750 metres of the landfill
k) history of work in dusty jobs and jobs with chemical fumes
l) socioeconomic status (ethnic origin, language, income, education, home ownership)
m) consent to abstract physician and hospital records

The draft questionnaire was pretested in 33 households containing 135 former residents who had lived between 500 and 750 metres from the landfill for less than three years from 1976 to 1980. These individuals were subsequently excluded from the survey. Feedback from the pretest suggested that the questionnaire was too long. Therefore, the number of questions on work history, alcohol intake, child development, and reproductive history was reduced.

B2.2 Administration of the Questionnaire

The interviews took place in the respondents' homes, and required an hour or more to complete. When a female head of household was unavailable, the interviewers followed a prespecified order in finding a substitute. Where a family had split up, there were several options. If one part of the family had remained in the study area, it was interviewed and the rest was excluded. If both parts of the family remained in the area, both were interviewed separately. If both parts of the family had moved (landfill residents only), an interview was sought only with the part that included the female head of household. When an interviewer failed to find a household at the address given, an attempt was made to find the family through driver licence records, local contacts, and leads picked up by the interviewers.

Publicity surrounding the landfill site and the study precluded the possibility of 'blinding' exposed respondents to the purpose of the interview. An attempt was made, however, to conceal the principal objectives of the study from the controls.

The interviewers were experienced in conducting studies on sensitive subjects. They were unaware of the hypotheses being tested and did not know which questions were 'decoys' to distract the respondents from more relevant ones. Each interviewer was assigned respondents from different subgroups. An informal survey taken after the field work was completed revealed that no distinct impressions or theories of cause and effect had emerged among the interviewers. The team leader of the interviewers checked all incoming questionnaires for completeness and internal consistency; callbacks were conducted whenever there were problems.

B3. ANALYSIS OF THE DATA

B3.1 Objectives

The analysis of the data was complex because six groups of landfill residents and two groups of controls were involved; numerous individual and groups of health problems were included as were tests of causation and tests for bias; and separate analyses for adults and children were carried out.

Essentially ten questions were asked of the data. The first question was the principal one addressed in the analysis plan:

1) Was there an increased risk for landfill area residents of developing health problems?

The nine additional questions developed for the analysis plan provided information related to the first question:

2) Was there an increased risk for landfill area residents by proximity to the landfill or duration of residence?*

3) Was a migrator bias caused by residents who moved away from the landfill neighbourhood?*

4) Are people who decide to live near the landfill less healthy for reasons that are unrelated to landfill exposures?*

5) Did the increased risk among landfill area residents develop before the landfill was closed?*

6) Were increased risks among landfill area residents also found for decoy health conditions?

7) Did landfill area residents have an increased risk for problems with pregnancy or birth defects?

8) Were there any other health problems for which landfll area residents might have an increased risk?

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* These were classified as subanalyses by the study team because they were conducted only for groups of health conditions for which an increased relative risk among landfill residents was observed in the analysis of data to address the principal question (i.e., main analysis).

9)Was there evidence of over-reporting or under-reporting recall bias from medical chart abstractions?

10) Are the health problems found in excess in landfill area residents likely to continue?

B3.2 Was There an Increased Risk for Landfill Residents of Developing Health Problems?

The first set of analyses was carried out specifically to provide data on the increased risk of landfill residents for certain health conditions. The analysis of these data involved comparisons of the health of the two major study groups: current, long-term landfill residents and the controls (see series 1000 to 6000 in Table 43).

Of particular interest was the question of whether or not the health problems that appeared in the workers study to be associated with landfill exposure are also observed in the residents study. There are five groups of these health problems and they are referred to as the 'main hypotheses' because they were derived from the hypotheses-generating workers survey. (See Table 42) A second question of interest concerned the extent, if any, to which health problems unrelated to those detected in the workers study (including the findings of an informal survey carried out by some of the residents) were associated with landfill exposures. These health conditions are referred to as 'secondary' hypotheses because they were identified in a less rigorous fashion than in the workers study and, therefore, have a lower probability of being caused by landfill exposure.

The statistical method used was the Cox model, which was also used to analyze the data in the workers study (see page 217). A landfill resident or control contributes 'risk time' only from the time of first exposure until the time he or she experiences the health condition being analyzed.*

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* The time at risk began with the year the household first moved into the landfill or control community only for current landfill residents and controls. For those who lived in either community before 1971, 1972 was taken as the first year at risk. Risk time was counted until the year of interview (1984). Only health problems whose first symptoms occurred after first residence in the landfill neighbourhood or control community were included in the analysis. When biologically related groups of health conditions were analyzed, only the first eligible event within the group was counted. Persons who reported having the health problems before moving into the landfill and control areas did not contribute risk time to the analysis. Smoking history, work history, and other risk factors with a cumulative impact were included even if they occurred before first residence in the community.

This model allows calculation of relative risk (see page 218) which is a measure of how much more likely landfill residents are to develop health problems than are controls. Main analyses of the main hypotheses were deemed positive if the probability value (p) for the relative risk was less than or equal to 0.01 (i.e., if the probability of the outcome occurring by chance alone was one in 100 or less).* The secondary hypotheses were deemed positive if the probability value of the relative risk was less than $\frac{0.05}{n}$; where n was the number of secondary hypotheses taken separately among adults and children.

B3.3 Was There an Increased Risk for Landfill Area Residents By Proximity to the Landfill or Duration of Residence?

The main study groups of current landfill residents who live close to and farther away from the landfill, and the controls, were analyzed for a trend in incidence rates of health problems related to proximity to the site. Separate analyses of duration of residence were then conducted to see whether or not the principal contribution to the trend came from the long-term residents. A trend that was stronger among long-term residents would support the conclusion that health problems were caused by exposure to the landfill. In the analysis of risk gradient, using the Cox model, a statistical parameter called linear trend (Z) is used to determine whether a gradient of risk was found with increasing distance from the landfill or by duration of residence. Also used in the analysis of a continuous distance variable for linear trend is a statistical parameter called 'chi square' (x^2).

B3.4 Was a Migrator Bias Caused by Residents Who Moved Away from the Landfill Neighbourhood?

The first analysis compared the former residents (i.e., movers) and the current landfill residents who lived in the area when liquid waste disposal was occurring. The second analysis compared the former landfill residents to the controls. If the former landfill residents had lower rates of health problems than current residents, and were more like the controls in health status, this would be evidence of a migrator bias artificially increasing the apparent risk associated with the landfill (i.e., would weaken the evidence for an increased risk for landfill area residents). If, on the other hand, the migrators were less healthy than the current residents, this would be evidence for a migrator bias artificially decreasing the apparent risk (i.e., supports the evidence of an increased risk for landfill residents). Evidence that the migrators were healthier than the current residents would tend to weaken positive results in the main analysis. Evidence that the migrators were less healthy would tend to strengthen positive results.

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* A (p) level of 0.01 was adopted to adjust for simultaneous multiple testing of five groups of health conditions and for four to five conditions within each organ system group among the main hypotheses for the residents study. This approach was appropriate for multiple testing by organ system, since the symptoms may be assumed to be different in different organ systems. However, it is conservative within organ systems, since in this case the independence of symptoms cannot be assumed.

B3.5 Are People Who Decide to Live Near the Landfill Less Healthy For Reasons that Are Unrelated to Landfill Exposures?

To determine whether the landfill neighbourhood attracted less healthy people, two comparisons were made of the health of recent landfill residents (who moved into the area after 1980) with the controls. If people who decided to live in the landfill neighbourhood were generally less healthy, the recent residents would report higher rates of health problems from 1972 to the present relative to the controls. If they reported increased rates of health problems only from 1981 to the present, this might represent either the effects of current landfill exposure or the underlying unhealthiness of those attracted to the area.

B3.6 Did the Increased Risk Among Landfill Area Residents Develop Before the Landfill was Closed?

The most important of the analyses conducted involved comparing current landfill residents with controls for health conditions that first occurred before 1981 in order to find out whether a risk developed during the period of most active liquid waste disposal at the landfill. If a risk decreased after the site was closed, removing the years 1981 to 1984 from the analysis would result in an increased relative risk in the 'before 1981' analysis. Other analyses involved comparisons between movers and current landfill residents and between recent residents and controls.

B3.7 Were Increased Risks Among Landfill Area Residents Also Found for Decoy Health Conditions?

The specificity of the associations between exposure to the landfill and the main health problems was examined. This analysis involved all pre-specified health problems in the questionnaire which were not included in other analyses for which there were 30 or more events reported in the main study groups. Health problems not thought to be related to environmental exposure were included in the questionnaire to act as decoy questions. This was a particularly important analysis because if many of these decoy health problems were found to be associated with landfill site exposure, then the credibility of all health problems found as being positively associated with living near the landfill would be reduced.

B3.8 Did Landfill Area Residents Have an Increased Risk for Problems With Pregnancy or Birth Defects?

Since adverse effects on pregnancy and childbirth are known to be sensitive indicators of chemical exposure, questions on reproductive experience were included in the questionnaire. Pregnancies occurring after first residence in the qualifying household were used in the analysis. The risk factors for the main study groups of landfill residents and controls were compared using simple univariate statistical techniques. The analysis examined stillbirth/spontaneous abortion, low birth weight, and any major or minor birth defects. These, too, were compared using simple univariate techniques as an initial screen. Multivariate analyses and possible clinical follow-up were planned, if any positive results emerged from univariate analyses.

B3.9 Were There Any Other Health Problems for Which Landfill Area Residents Might Have an Increased Risk?

A few adult and child health conditions were not derived from the main or secondary hypotheses but were of interest in the residents study because a possible association between these health effects had been related to chemical exposures elsewhere. These effects, which consisted of four groups of health problems for adults and three for children, were also analyzed using the Cox model, but were not included in any of the subanalyses.

B3.10 Was There Evidence of Over-Reporting or Under-Reporting Recall Bias from Medical Chart Abstractions?

The approach taken to medical chart abstraction in the residents study was designed to correct two problems that had been encountered in the abstraction of workers' medical charts. In order to blind abstractors to the health problems reported by the study subjects and to obtain data on both under- and over-reporting of respondents, a limited number of health conditions was abstracted from the medical records of landfill residents and controls.

The health problems to be examined in the chart abstraction study met specified criteria. All conditions listed in the questionnaire were grouped by organ-system or biologically-related cluster. For adults, two groups thought to be least relevant among a young population, cardiac and arthritic complaints, were excluded. The remaining conditions were divided into nine groups. Two conditions were then sampled at random from each of these nine groups. The first condition selected was designated for abstraction, and the second served as an alternate that was usually used in situations where there proved to be too few reports of the first health condition selected for abstraction.

The nine health problems eventually selected through the above process for the abstraction of the medical charts of adult landfill and control residents were pneumonia (including bronchopneumonia), nosebleeds (not from injury), getting up more than once at night to urinate, loss of weight, recurrent or severe problems with unusual acne, prolonged, irritated, sore throat, ringing in the ears or tinnitus, constant fatigue, lethargy or drowsiness, and numbness, tingling, prickling, or loss of sensation in arms or hands.

For children, there were only five groups of conditions for which a sufficient number of events were reported to warrant sampling (respiratory, dermal, head and neck, developmental conditions, and a miscellaneous category of other health conditions reported in the questionnaire). The conditions selected for child chart abstractions were asthma, food allergies, recurrent or severe problems with skin rashes or hives, red, itchy, watery, sore, dry or inflamed eyes, and problems with normal physical growth or development.

Medical chart abstraction was restricted to persons in the main study groups of current landill residents and controls who had reported having one or more of the selected conditions since 1972, and the doctors whom they had seen for the health problems were available for followup in the Hamilton area. The nurse abstractors did not know if they were abstracting the medical charts of landfill residents or controls. In addition, a random sample of 60 persons (40 adults, 20 children), who had reported none of the selected health problems was selected. In this situation the records of the physician they had most often consulted for other conditions were examined.

Conclusions regarding possible over-reporting were based on the proportion of reported conditions that were not confirmed and conclusions regarding under-reporting were based on the proportion of unreported conditions that were confirmed or possibly confirmed (i.e., problems found in the medical charts but not reported on the questionnaire). If the landfill residents had been found to over-report their health problems compared to the controls, this would be evidence of a recall bias in the study and would question the credibility of all the findings.

The abstraction process was used to assess recall bias, not the accuracy of reporting. Because not all medical records were exhaustively examined, because physicians may not have recorded all symptoms, and because somewhat arbitrary definitions of confirmation and non-confirmation were used, the estimates of proportions of under- and over-reporting are meaningful only for comparison between study groups and not as estimates of absolute reporting accuracy.

B3.11 Are the Health Problems Found in Excess in Landfill Area Residents Likely to Continue?

Analyses were conducted to assess whether or not the health problems found in excess among the residents currently living near the landfill would be likely to continue to affect their well-being. These analyses included comparisons of the current prevalence of health problems found in landfill residents, controls, and movers, the rates of persistence for these conditions among the various groups of households, and the Canada Health Survey questions on long-term health problems.

C. RESULTS

C1. DESCRIPTIVE STATISTICS

C1.1 Rates of Response

Interviews were completed in 82.2 per cent of the households currently living near the landfill (1000 through 4000 series), in 75.3 per cent of the mover households, in 80.3 per cent of recent landfill residents, and in 67.8 per cent of the control households. The differences in response rates are readily explained by the degree of self-interest each group would have had in the results. Unfortunately, the control group's lower response rate leaves open the possibility of a volunteer/non-respondent bias affecting the study results. The reason most often given for refusal in all groups was "too busy" or "not interested." Refusals for reasons of ill-health were rare; nonetheless, it is possible that other refusals were related to health status in some unknown way.

C1.2 Comparability of Households Living Near the Landfill and the Control Households

C1.2(a) Sociodemographic Characteristics. In 1983 the modal income for the main groups of landfill households (1000 to 4000 series), controls, and mover households was $30-39,999 and $20-29,999 for recent landfill households. Controls had a higher overall income. Only 6.7 per cent of control households had incomes of less than $20,000, while 35.2 per cent had $40,000 or more. Among landfill households, 12.8 per cent had incomes of less than $20,000, while 21.2 percent had $40,000 or more. These differences do not suggest that the main study groups fall into separate income quintiles within the Canadian range. In Canada, differences in health status have been measured between income groups but not within them.

The lower income distribution in landfill households was found to correspond to a higher proportion of families renting rather than owning their houses. The criteria that had been used to match communities in the selection of controls had masked these differences. However, no other Hamilton neighbourhood would have made a better match.

The size of the respondents' families and their degree of co-operation were similar. The interviewers found no difference in the proportion of respondents in each group who had substantial difficulties understanding the questionnaire.

The modal level of education for each group was completion of grades 11-13. Once again, the distribution was higher among the controls. Nineteen per cent had completed grade 10 or less, while 31.6 percent had completed college or other post-secondary institutions. Among landfill households, 29.1 per cent had completed grade 10 or less, while 21.7 per cent had completed college or other post-secondary education. The landfill group had a higher proportion of blue-collar than white-collar workers, while the control group had the reverse. Fortunately, these differences were not reflected in the experience of dusty jobs or work with industrial chemicals. Among landfill residents, 29.8 per cent reported work on dusty jobs compared to 25.8 per cent of the controls. Exposure to chemical fumes and gas was reported by 24.6 per cent of the landfill residents and 21.4 per cent of the controls.

No differences were seen among the groups in the proportion of people born outside of Canada, and only small differences were seen in the proportion of individuals whose first language was English (77.9 per cent of landfill residents, 80.8 per cent of controls). The most common second language of both communities was Italian.

The modal age at date of first residence was 26-30 years for all groups. The controls were slightly older than the landfill residents: 11.1 per cent of controls and 9.7 per cent of landfill residents were over 45, while 29.1 per cent of landfill residents and 20.5 per cent of controls were under 25 at first residence. Sexual balance was similar: 47.7 per cent of landfill adults were male and 49 per cent of controls were male. Among children, the age distribution at first residence was highly comparable for landfill residents and controls, as was the sexual ratio: 49.7 per cent of landfill residents' children were male, while 48.7 per cent of control children were male.

C1.2(b) Drinking and Smoking Habits. Statistical analysis of the smoking and drinking habits of adults was confined to the landfill and control groups. No differences in drinking habits were found. Forty per cent of adult landfill residents but only 26.8 per cent of controls were current daily smokers. Approximately 60 per cent of landfill residents and 48 per cent of controls had been daily smokers at some time. Current smokers in both groups had begun smoking at a comparable age.

C2. ANALYSIS OF THE DATA

C2.1 Was There an Increased Risk for Landfill Area Residents of Developing Health Problems?

C2.1(a) Health Problems Identified in the Workers Study. In the analysis of these main hypotheses (i.e., health problems which had been found in excess in landfill workers) the conditions were divided into five groups. Only those conditions whose first symptoms developed after first moving into the landfill or control neighbourhood were included. Only the long-term current landfill residents (1000 - 4000 series) and controls (5000 - 6000 series) were included in this analysis.

Adults. It is seen from Table 44 that there are strongly positive associations between living near the landfill and health problems in four of the groups: respiratory conditions, skin conditions, certain central nervous system, and mood symptoms. The principal contributing conditions to the respiratory group were attacks of bronchitis, shortness of breath, and periods or episodes of cough and phlegm lasting for three weeks or more. Recurrent or severe problems with scaly, dry or itchy skin was the principal contributor to the skin group. Frequent or severe headaches, frequent dizziness or blurred vision, and constant fatigue,

Table 44: **Risk Of Developing Health Problems Associated With Living Near the Landfill Site for Adults**

Condition[1]	Confounding Variables[2]	N of Events[3]		Eligible Subjects[4]		Person Years[5] at Risk		Relative[6] Risk	p(RR)[7]
		Landfill Residents	Controls	Landfill Residents	Controls	Landfill Residents	Controls		
Combined Respiratory	all	149	91	997	839	6970	6753	1.56	<.001
(a) attacks of bronchitis	all	44	21	956	804	7004	6689	2.07	.004
(b) chronic bronchitis	all	8	7	982	830	7375	6936	1.04	.47
(c) shortness of breath	all	48	21	972	830	7145	6884	2.00	.005
(d) cough & phlegm	all	88	53	972	824	7079	6766	1.55	.007
Combined Skin	all	130	68	997	839	6984	6763	1.76	<.001
(a) recurrent or severe problems with scaly, dry, or itchy skin	b	59	23	964	814	7022	6722	2.32	<.001
(b) recurrent or severe problems with skin rashes or hives	b	31	15	980	817	7288	6796	1.93	.05
(c) recurrent or severe problems with unusual acne	b,e,f	8	5	990	834	7419	6965	1.92	.13
(d) recurrent or severe problems with boils, warts, cysts	b	36	23	979	827	7259	6849	1.53	.06
(e) white or dark patches on the skin	b	18	10	992	830	7409	6924	1.66	.09
Combined Central Nervous System	all	170	67	997	839	6809	6764	2.29	<.001
(a) frequent or severe headaches	a,b,e,f	106	41	914	767	6465	6257	2.21	<.001
(b) frequent dizziness or blurred vision	b,f	38	13	992	834	7362	6949	2.65	.01
(c) constant fatigue, lethargy, drowsiness	b,e	63	22	986	833	7203	6917	2.54	<.001
(d) problems with balance, co-ordination, reaction time, clumsiness	b	13	8	987	833	7398	6952	1.54	.17
Combined Mood	all	129	66	997	839	7035	6740	1.70	<.001
(a) trouble sleeping	b,c,f	63	41	974	819	7101	6738	1.30	.10
(b) frequent feelings of anxiety or depression	a,b	62	23	966	822	7073	6791	2.50	<.001
(c) frequent feelings of irritability	b,c,e	48	20	983	833	7252	6869	2.22	.01
(d) frequent feelings of hyperactivity, restlessness, trouble sitting still	b,c,e	17	8	988	838	7350	6898	1.96	.08
(e) learning or memory disorders	none	4	1	997	839	7483	7027	NA[8]	.12
Muscle Weakness	none	15	8	997	838	7456	6999	1.36	.09
(a) arms, legs, hands or feet									

Notes:

1 The main hypotheses are these target health problems identified from the workers health study.
2 The confounding variables entered into the Cox proportional hazards models for each of the health conditions are:

Respiratory Conditions		Skin Conditions		Narcotic and Mood Symptoms and Muscle Weakness	
age (linear +5 year categories)	(a)	age (linear +5 year categories)	(a)	age (linear +5 year categories)	(a)
sex	(b)	sex	(b)	sex	(b)
ever smoked daily	(c)	ever worked with chemical fumes or gases	(e)	ever smoked daily	(c)
ever worked in a dusty job	(d)	highest level of schooling	(f)	ever worked with chemical fumes or gases	(e)
ever worked with fumes or gases	(e)			highest level of schooling	(f)
highest level of schooling	(f)				

3 The total number of health conditions reported on the questionnaire by current adult landfill residents and controls.
4 The total number of eligible landfill residents and controls reporting the health conditions (i.e., series 1000, 2000, 3000, 4000, 5000, 6000 shown in Table 43).
5 Person-years at risk were calculated from the year the household first moved into the landfill or control community until the year of interview (1984).
6 The association between living near the landfill and developing the health problem gets stronger as the numerical value of the relative risk gets larger. For example, a relative risk of 2.00 means that the landfill residents are twice as likely as the controls to develop the health condition.
7 "p(RR)" is the probability value of the relative risk (based on a Z-distribution, one-tailed). It is a measure of statistical significance that shows if the relative risk occurred for the reason being investigated or by chance alone. For example, a p value of <.001 in this table means the probability that the increased relative risk accurred by chance alone is one in one thousand.
8 Not enough reported health problems to be analyzed.

lethargy, or drowsiness were the principal contributors to the central nervous system group. Frequent feelings of anxiety or depression and frequent feelings of irritability were the principal contributors to the mood group. Muscle weakness was not found to be associated with living near the landfill and was excluded from further analysis.

Children. Table 45 shows that for children living near the landfill positive associations were seen for skin, mood and, particularly, certain central nervous system symptoms. In contrast to adult landfill residents, respiratory conditions were less closely associated. The principal contributing conditions to the skin group were recurrent or severe problems with boils, warts, cysts and recurrent or severe problems with scaly, dry, itchy skin. Frequent or severe headaches was the symptom contributing most events to the central nervous system group. The principal mood symptoms were hyperactivity, restlessness, and trouble sitting still. The most frequently reported respiratory symptoms were periods or episodes of cough or phlegm lasting for three weeks or more. As with the adults, muscle weakness was not found to be associated with exposure to the landfill site and was excluded from further analysis.

C2.1(b) Health Problems Identified From Other Sources. These secondary hypotheses consist of health conditions that were identified in an informal health survey previously conducted by the Residents Association, and other problems of physical and emotional development in children. As mentioned previously, the conditions identified in the workers survey were derived from a rigorous hypothesis-generating study and, therefore, have a higher probability of being associated with landfill exposure than do these secondary hypotheses.

Adults. A Cox model analysis was conducted comparing the current landfill residents (1000-4000 series) with controls (5000-6000 series) for ten secondary hypotheses: hayfever; asthma, wheezy or whistling chest for most days or nights throughout the year; five or more colds per year; nosebleeds (not from injury); unusual nasal irritation or discharge; throat infections or prolonged, irritated, sore throat; red,itchy, watery, sore, dry, or inflamed eyes; numbness, tingling, prickling, or loss of sensation in arms, legs, hands, or feet; and difficulty in starting a pregnancy (females only). Only one condition, red, itchy, watery, sore, dry, or inflamed eyes, was found to be statistically significantly elevated in the landfill group.

The gradient analyses discussed below showed a higher risk of developing red, itchy eyes among landfill residents as compared to controls, particularly for long-term residents. Among short-term residents, there was no evidence of risk reduction by increasing distance from the landfill. No differences in incidence rates of the eye problem were found in movers as compared with current landfill residents. A higher incidence rate was found in movers as compared to controls but this was not statistically significant. This finding was expected because the movers appear to be like current landfill residents. Another possible explanation is the methodological problem of having to include in the analysis the follow-up time after the movers left the landfill neighbourhood, which might mask the original

Table 45: Risk of Developing Health Problems Associated with Living Near the Landfill Site for Children

Condition[1]	Confounding Variables[2]	N of Events[3]		Eligible Subjects[4]		Person Years[5] at Risk		Relative[6] Risk	p(RR)[7]
		Landfill Residents	Controls	Landfill Residents	Controls	Landfill Residents	Controls		
Combined Respiratory	all	119	74	973	752	6161	5312	1.31	.044
(a) attacks of bronchitis	a	49	36	957	740	6301	5322	.99	.51
(b) chronic bronchitis	none	5	2	970	748	6571	5532	1.57	.30
(c) shortness of breath	none	25	11	972	750	6520	5507	1.87	.042
(d) cough & phlegm	c	65	31	963	747	6308	5450	1.68	.014
Combined Skin	all	141	69	974	752	6161	5353	1.64	<.001
(a) recurrent or severe problems with scaly, dry, or itchy skin	none	33	15	966	747	6424	5475	2.07	.014
(b) recurrent or severe problems with skin rashes or hives	none	36	17	974	743	6505	5448	1.71	.038
(c) recurrent or severe problems with unusual acne	a,b,c	15	11	974	752	6583	5523	.71	.21
(d) recurrent or severe problems with boils, warts cysts	a,c	62	22	971	748	6472	5493	2.24	<.001
(e) white or dark patches on the skin	none	6	6	972	751	6590	5546	.95	.47
Combined Central Nervous System	all	88	27	974	752	6315	5476	3.17	<.001
(a) frequent or severe headaches	a,b	77	24	967	749	6309	5451	3.13	<.001
(b) frequent dizziness or blurred vision	a,b	6	1	973	752	6605	5567	3.86	.11
(c) constant fatigue, lethargy, drowsiness	none	10	4	973	752	6577	5563	2.50	.09
(d) problems with balance, co-ordination, reaction time, clumsiness	c	4	1	967	749	6550	5541	2.08	.26
Combined Mood	all	69	27	974	752	6373	5464	2.07	<.001
(a) trouble sleeping	none	10	3	973	751	6589	5558	2.66	.07
(b) frequent feelings of anxiety or depression	a,c	10	2	973	752	6587	5558	2.92	.09
(c) frequent feelings of irritability	a,c	16	1	974	751	6569	5560	8.36	.021
(d) frequent feelings of hyperactivity, restlessness, trouble sitting still	a,b,c	36	11	955	741	6365	5441	3.10	<.001
(e) learning or memory disorders	a	13	11	970	747	6550	5495	1.17	.36
Muscle Weakness									
(a) arms, legs, hands, or feet	a	7	2	975	752	6591	5562	4.50	.08

Notes:

1 The main hypotheses are these target health problems identified from the workers health study.
2 The confounding variables entered into the Cox proportional hazards models for each of the health conditions are:

Respiratory Conditions		Skin, Narcotic, Mood and Muscle Weakness	
age (linear +5 year categories)	(a)	age (linear +5 year categories)	(a)
sex	(b)	sex	(b)
family income	(c)	family income	(c)
any parent a daily smoker	(d)		

For 3-7, see explanations on Table 44.

effect of exposure to the landfill. Comparison of recent landfill residents to controls (1972-84) did not reveal any evidence that those living near the landfill after it was closed were more prone to developing this eye problem than the controls.

Children. In an analysis of the ten secondary hypotheses, for children living near the landfill compared to the controls two conditions reached statistical significance: five or more colds per year and red, itchy, watery, sore, dry, or inflamed eyes. The analyses of the secondary hypotheses were an important supplement to the analysis of data for children because the main hypotheses were identified from the health study of landfill workers and, therefore, were more likely to be found in adults.

There was no evidence of a trend of increased risk of red, itchy eyes for children in any of analyses discussed below of risk by proximity to the landfill or duration of residence. Comparison of movers versus current landfill residents showed borderline evidence of reduced risk among the movers. Comparison of movers with controls showed borderline evidence of elevated risk among movers. The recent residents had higher incidence rate of red, itchy eyes than the controls, but this did not reach a high level of statistical significance.

A trend of increased risk of five or more colds per year was seen in all three gradient analyses for children. Only borderline levels of statistical significance appeared in the overall analysis and in the analysis confined to long-term residents. No statistical trend was seen in the analysis confined to short-term residents because of the smaller number of events and person-years among the short-term residents. The analyses of migrator effects showed no evidence of bias.

C2.2 Was There an Increased Risk for Landfill Area Residents by Proximity to the Landfill or Duration of Residence?

The purpose of these gradient analyses was to examine whether an increased incidence of health problems was related to the distance of a household from the landfill site or to the length of time residents lived in the landfill neighbourhood. Analyzing for the effect of proximity involved two approaches. The first was a three way comparison among (1) residents living within 500 metres of the landfill (2) residents living 500 to 750 metres from the landfill and (3) controls. A second analysis of proximity to the landfill involved the measurement of a continuous distance variable (i.e., detailed exposure distance) for each household from the site.

The analysis of duration of exposure compared the incidence of health problems between long-term landfill and control residents (1000, 3000, and 6000 series) and the short-term landfill and control residents (2000, 4000, and 5000 series).

The statistical methods, the health conditions included, and the confounding variables were similar to those used in the main analyses. As mentioned earlier, a statistical parameter called linear trend is used to determine whether a gradient of risk was found with increasing levels of exposure. The probability value (p) is used to determine whether the linear trend is statistically significant (i.e., $p<0.01$) or has occurred by chance ($p>0.01$).

Adults. The first analysis of a gradient by general proximity of a household to the landfill is shown in Table 46. The results show a higher risk of respiratory, skin, certain central nervous system, and mood problems in households near the landfill. A linear trend in crude incidence rates was evident for respiratory, certain central nervous system, and mood symptoms. The crude incidence rates of skin symptoms did not show a consistent trend. An analysis was done to determine whether or not skin problems might be more closely related to direct skin contact through recreational activities in and around the landfill area rather than to proximity of household. The results confirmed that recreational contact was a more important factor than location of household because 28.6 per cent of landfill residents reporting such recreational activities also reported one or more skin problems, while only 11.9 per cent of those not reporting these activities reported skin symptoms.

Table 47 shows the results of the second approach to the analysis of a gradient effect by measuring the continuous distance variable for each house from the closest edge of the landfill. This allowed the calculation of a linear trend within the landfill residents' group free of confounding due to differences from the controls. Table 47 shows that the risk for respiratory, certain central nervous system, and mood symptoms among long-term residents decreased continuously as the distance from the landfill was increased. The trend for skin symptoms was much weaker. The trends among short-term residents were weak, and did not show a reduction of risk with increased distance from the site. These results suggest a gradient effect by proximity to the landfill site for the long-term residents, which is consistent with the conclusion from the first approach of comparing households located within 500 metres and 500 -750 metres from the landfill and the controls.

Table 48 presents the results of the analysis of a gradient effect for long-term residents only. Long-term residents are those who lived adjacent to the landfill or in the control community for three or more years during the peak period of dumping (1000, 3000, and 6000 series). Since linear trends are evident for the incidence of all health conditions shown in Table 48, it would appear that there was a higher risk of developing health problems for households that are located closer to the landfill and have lived there for a longer period of time.

A similar analysis for duration of exposure was carried out for short-term residents who spent less than three years in the landfill or control community during the peak period of dumping (2000, 4000, and 5000 series). No trend between higher risk and living closer to or farther from the landfill could be seen for short-term residents.(2)

Table 46: **Risk Gradient By General Proximity Of Residence To Landfill Site: Short and Long-Term Adult Residents**[1]

Condition	Location of Residence	N of Events	Incidence[2] (Events per 1000 person-years)	Z (linear trend)[3]	p[4]
1. Combined Respiratory	(a) within 500 metres of landfill	61	25.6	4.01	< .001
	(b) 500-750 metres from landfill	88	19.2		
	(c) control area	91	3.5		
2. Combined skin	(a) within 500 metres	44	18.1	3.16	< .001
	(b) 500-750 metres	86	18.9		
	(c) control area	68	10.1		
3. Combined Central Nervous System	(a) within 500 metres	67	28.9	5.89	< .001
	(b) 500-750 metres	103	23.0		
	(c) control area	67	9.9		
4. Combined Mood	(a) within 500 metres	58	24.1	4.49	< .001
	(b) 500-750 metres	71	15.7		
	(c) control area	66	9.8		

Notes:

[1] Short-term residents are defined as groups 2000 and 4000 and long-term residents as groups 1000 and 3000 as shown in Table 43.

[2] Crude estimates. Values used to calculate linear trend within the Cox model are not recoverable from the computer.

[3] Z (linear trend) is a statistical parameter used to determine whether a gradient of risk was found with increasing levels of exposure (i.e., distance from the landfill). A higher numerical value represents a stronger linear trend.

[4] p is the probability that the linear trend has occurred by chance, which in this table is shown to be less than one in 1,000.

Table 47: Risk Gradient by Continuous Distance Variable[1]

Condition	x^2(linear trend)[2]	p[3]	Risk Reduction[4] per 100 Metres from Landfill
Long-term Landfill Residents: Adults			
1. Combined Respiratory	4.74	.015	-17%
2. Combined Skin	0.79	.186	-8%
3. Combined Central Nervous System	6.66	.005	-18%
4. Combined Mood	4.94	.013	-18%
Short-term Landfill Residents: Adults			
1. Combined Respiratory	.14	.65	+4%
2. Combined Skin	.74	.80	+11%
3. Combined Central Nervous System	1.61	.90	+12%
4. Combined Mood	.27	.70	+5%

Notes:

[1] This analysis included all current landfill households in the long-term resident groups (1000 and 3000) and in the short-term resident groups (2000 and 4000) as shown in Table 43. The risk gradient in this table is more precise than that used in Tables 46 and 48 because the distance of each household was measured. The results shown here are for adults only.

[2] X^2 (linear trend) is a statistical parameter called 'chi square'. The higher the numerical value shown, the stronger the linear trend towards a higher risk of developing the health problem by distance from the site.

[3] p is the probability that the trend towards a higher risk of developing the health problem is statistically significant and has not occurred by chance.

[4] Based on the slope of the exponential coefficient for distance from landfill given confounding variables, in the Cox proportional hazards model. This should be interpreted as "for each 100 metres from the landfill, the risk decreased X% from the level 100 metres closer."

Table 48: **Risk Gradient by General Proximity of Residence to Landfill Site: Long-Term Adult Residents Only**

Condition	Location of Residence	N of Events	Incidence (Events per 1000 person-years)	Z(linear trend)	p
1. Combined Respiratory	(a) within 500 meters of landfill	44	26.1	3.73	<.001
	(b) 500-750 metres from landfill	45	14.5		
	(c) control area	69	12.4		
2. Combined Skin	(a) within 500 metres	34	19.8	3.04	<.001
	(b) 500-750 metres	52	17.0		
	(c) control area	56	10.1		
3. Combined Central Nervous System	(a) within 500 metres	52	32.3	5.44	<.001
	(b) 500-750 metres	58	19.2		
	(c) control area	57	10.3		
4. Combined Mood	(a) within 500 metres	42	24.7	3.27	<.001
	(b) 500-750 metres	35	11.2		
	(c) control area	57	10.3		

Notes:

See explanations on Table 46.

Children. The results of an analysis of a gradient effect in the incidence of health problems among children by general proximity of household to the landfill, are shown in Table 49. These analyses are less valid for children than adults because attendance at neighbourhood schools and outdoor play tend to make location of the household a less valid predictor of each child's exposure to the landfill site. Nevertheless, Table 49 shows that the linear trend was statistically significant for skin and central nervous system symptoms and borderline for mood symptoms.

As shown in Table 50, when the degree of risk to children was analyzed by the continuous distance variable, none achieved adequate levels of statistical significance to warrant further examination.

Table 51 presents the results of the analysis of a gradient effect by duration of exposure to children of long-term residents only. A trend in the direction of the probable exposure gradient was seen for respiratory, skin, and mood symptoms but only skin symptoms met the criteria for a statistically significant linear trend. This result is in contrast to the results of the analysis of the data on adults where linear trends were found for all but skin symptoms. As was the case among the adult respondents, skin symptoms were closely associated with recreational activities near the landfill site. Twenty-four per cent of children in the landfill neighbourhood reporting such activities also reported one or more skin symptoms, while thirteen per cent reporting no such recreational activities reported skin symptoms.

Analysis of a gradient effect by duration of exposure for children of short-term residents only was also carried out but no statistically significant linear trend was seen. The most clearly discernible trend was for central nervous system symptoms.(3)

Overall, only skin symptoms met the preset criteria for a linear trend among combined long- and short-term landfill households, as well as in long-term households alone.

C2.3 Was a Migrator Bias Caused By Residents Who Moved Away from the Landfill Neighbourhood?

The purpose of these analyses was to determine what type of bias, if any, was involved in the survey because of former residents who had moved away from the landfill neighbourhood.

Adults. When the former landfill residents (8000 series) were compared (for 1976-1980) to the current landfill residents and to the controls, it was found that the health of the movers was more like that of the current landfill residents than that of the controls. The incidence of skin, central nervous system, and mood conditions among the movers was similar to that among the current landfill residents, although the movers suffered fewer respiratory ailments. The comparison between former landfill residents and controls showed the reverse: movers had a much higher rate of incidence of skin, central nervous system, and

Table 49: Risk Gradient by General Proximity of Residence to Landfill Site: Short and Long-term Residents' Children

	Conditions	Location of Residence	N of Events	Incidence (events per 1000 person-years)	Z(linear trend)	p
1.	Combined Respiratory	(a) within 500 metres of the landfill	42	19.0	1.40	.081
		(b) 500-750 metres from the landfill	77	19.5		
		(c) control area	74	13.9		
2.	Combined Skin	(a) within 500 metres	60	28.2	3.98	<.001
		(b) 500-750 metres	81	20.1		
		(c) control area	69	12.9		
3.	Combined Central Nervous System	(a) within 500 metres	31	13.9	4.52	<.001
		(b) 500-750 metres	57	14.0		
		(c) control area	27	4.9		
4.	Combined Mood	(a) within 500 metres	22	9.8	2.28	.011
		(b) 500-750 metres	47	11.4		
		(c) control area	27	4.9		

Notes:

See explantions on Table 46.

Table 50: **Risk Gradient by Continuous Distance Variable**

Condition	x^2(linear trend)	p	Risk Reduction per 100 Metres from Landfill
Long-term Landfill Residents: Children			
1. Combined Respiratory	.83	.180	-9%
2. Combined Skin	.87	.175	-8%
3. Combined Central Nervous System	.16	.345	-4%
4. Combined Mood	1.12	.145	-13%
Short-term Landfill Residents: Children			
1. Combined Respiratory	.67	.707	+12%
2. Combined Skin	.43	.757	+8%
3. Combined Central Nervous System	1.74	.099	-21%
4. Combined Mood	.00	.486	+1%

Notes:

See explanations in Table 47.

Table 51: **Risk Gradient by General Proximity of Residence to Landfill Site: Long-term Residents' Children Only**

Condition	Location of Residence	N of Events	Incidence (Events per 1000 person-years)	Z (linear trend)	p
1. Combined Respiratory	(a) within 500 metres of of landfill	30	17.8	1.68	.047
	(b) 500-750 metres from landfill	45	15.7		
	(c) control area	56	12.5		
2. Combined Skin	(a) within 500 metres	46	28.5	4.89	.001
	(b) 500-750 metres	53	18.1		
	(c) control area	49	10.8		
3. Combined Central Nervous System	(a) within 500 metres	23	13.5	3.89	.001
	(b) 500-750 metres	43	14.5		
	(c) control area	23	5.0		
4. Combined Mood	(a) within 500 metres	17	9.9	2.28	.011
	(b) 500-750 metres	29	9.7		
	(c) control area	21	4.5		

Notes:

See explanations on Table 46.

Table 58: **Current Persistence and Prevalence of Individual Health Problems for Children**

Condition	Groups(a)	First Had Condition After Residence in Landfill/ Control Area: Still Have It	First Had Condition After Residence in Landfill/ Control Area: Don't Have it now	Never Had Condition	Prevalence[d] $x^{2(b)}$	Prevalence[d] $p^{(c)}$	Persistence[e] $x^{2(b)}$	Persistence[e] $p^{(c)}$
1. cough and phlegm	exposed	43	22	898	7.75	.0053	2.77	.096
	controls	15	16	716				
2. recurrent or severe problems with boils, warts, cysts	exposed	29	32	909	.833	.36	5.79	.016
	controls	17	5	726				
3. frequent or severe headaches	exposed	69	7	890	14.85	.00012	.02	.896
	controls	22	2	725				
4. frequent feelings of hyperactivity, restlessness trouble sitting still	exposed	34	2	919	6.96	.008		1.0
	controls	11	0	730				
5. red, itchy eyes	exposed	73	19	862	22.05	.00001	2.66	.103
	controls	18	10	715				
6. five or more colds per year	exposed	79	26	840	14.94	.0001	10.22	.0014
	controls	27	27	673				

Notes:

See explanations in Tables 55 and 57.

The issue of current prevalence can be examined by comparing in Tables 55 and 56 the proportion of those reporting still having the condition with the sum of those who never had the condition and those who had it but no longer did at the time of interview. It can be seen that the current prevalence of the conditions of interest was increased among landfill area adults and children as compared to controls for all four groups of health conditions. In Tables 57 and 58, which show the results of the same analysis carried out on individual health conditions, it can be seen that, in each case, the current prevalence of the condition was greater among the landfill area residents than the controls except for recurrent or severe problems with boils, warts and cysts for children. It is to be expected that the prevalence of health conditions will remain higher among landfill area residents than controls because a higher incidence of these conditions was reported by landfill area residents to begin with. It is important to note, however, that the conditions appear to be disappearing at similar rates among landfill residents and controls.

As another check on the overall state of health of the respondents, a number of questions from the Canada Health Survey assessing the current prevalence of a broad range of long-term health problems (not necessarily related to environmental exposures) were included in the questionnaire. For the 14 conditions for which sufficient data were obtained (for either adults or children), analysis showed no major differences between the landfill and control groups. The only unexpected difference was in relation to trouble with bones and joints among adults. This difference is unexplainable on the basis of exposure to the landfill site. It may represent a random false positive result.

In summary, the health problems found in excess among the landfill residents during 1976-1980 were, predictably, still found in excess, but to a lesser extent, at the time of the interview in 1984. However, the duration of these conditions was no greater among those exposed to the landfill than among the controls for three of the four main groups of health conditions. It is likely that the rate of persistence of the conditions found in excess during exposure to the landfill site will continue to decrease with time.

D. DISCUSSION

Nine criteria, which were agreed upon before analysis of the data began, were used to assess the validity of the association between living near the landfill site and the health problems identified: strength of association (which was determined by the magnitude of relative risk and the level of statistical significance of the findings); consistency with the results of the workers study; gradient of risk with location of residence and time of exposure; evidence of migrator bias; no evidence that less healthy people moved to the landfill area; risk that first occurred when the site was open; the specificity of the observed health conditions to those hypothesized; and the absence of recall bias. The latter two criteria apply generally to all conditions rather than to each condition individually.

mood conditions, but not of respiratory conditions. These results suggest the existence of a migrator bias that supports the evidence for an increased risk for landfill residents.

Children. When children who had moved away from the landfill neighbourhood were compared with current residents and with controls, no statistically significant differences were seen between movers and current residents for any of the four major groups of health conditions. Analysis showed differences in relative risk between movers and controls for skin, central nervous system, and mood conditions, but no elevated risk was noted for respiratory conditions. Overall, these data again suggest that the health of the movers was more like that of the current landfill residents than that of the controls.

C2.4 Are People Who Decide to Live Near the Landfill Less Healthy for Reasons that Are Unrelated to Landfill Exposures?

In order to determine whether the landfill site area attracted less healthy people, the controls were compared with recent landfill residents (persons who moved into the landfill area after the site was closed). All health problems reported from 1972 to the time of interview were included, whether or not they occurred before the household had moved to the qualifying location. This approach allowed for a concurrent analysis, based on the premise that the health of the two groups ought to be similar unless the landfill site area attracted residents who were less healthy than other members of the community.

Adults and Children. No statistically significant difference in incidence rates was found for any of the main groups of conditions. The relative risk was approximately equal to 1.0 for each of the main groups of conditions. There is no evidence, therefore, that the landfill site area attracted less healthy adults or children as residents.

C2.5 Did the Increased Risk Among Landfill Area Residents Develop Before the Landfill Was Closed ?

Several analyses were designed to determine if increased relative risks for landfill residents emerged before the landfill closed.

Adults. To find out whether a statistically detectable risk developed during the time the landfill was open to the disposal of toxic waste, the main analyses of both primary and secondary hypotheses were carried out to include only the health problems that first occurred before 1981. Since most of the health problems contributing to the respiratory, skin, mood and central nervous system groups (and red, itchy eyes) were acute rather than chronic, it could be expected that important differences in incidence rates should have emerged before the site closed (and, presumably, exposure declined) and this is what was seen.

Elevated relative risks were found in landfill residents as compared to controls for respiratory, skin, and central nervous system conditions as well as for mood symptoms and red, itchy eyes when health problems first occurring before

1981 were considered. These findings are shown in Table 52 and they indicate that the increased risk of developing health problems first occurred during the period of active operation of the landfill.

A question related to the occurrence of the increased risk before 1981 is the comparable size of the relative risk of first developing health problems after 1981. Although no analyses were conducted specifically to address this question, it is possible to obtain some insight by a rough comparison of the size of the relative risks reported for health conditions in Table 44 with those reported in Table 52. It can be seen that the overall relative risks shown in Table 44 for respiratory, skin and central nervous system conditions are lower than the relative risks shown in Table 52 for the first occurrence of these conditions before 1981. Therefore, there is a greater contribution to the size of the relative risk before rather than after 1981. This is also reflected in a higher proportion of landfill area residents compared to controls first reporting the health condition before 1981 in Table 52 versus the proportion shown in Table 44 (after removing the pre-1981 events).

A second analysis compared movers and current landfill residents for all health problems that developed before 1981, when the landfill site was open and most of the people who subsequently moved were still living near it, to all the events from 1981 to 1984, when the site was closed and the movers had left the area. Table 53 shows that in all cases, the relative risk for current landfill residents as compared to movers increased between the two periods but, with the exception of respiratory complaints, none of these relative risks is statistically significant. The movers were complaining of a higher rate of first events of the target health problems than the current landfill residents before they left the area, but fewer thereafter. This may be interpreted as a migrator bias that would support the evidence of an increased risk for landfill residents because if the movers were included with current landfill residents in a comparison with controls, the estimated relative risks would have increased even more.

In a third analysis, recent residents and controls were compared to determine whether or not there was any evidence of effects of exposure to the landfill after the site was closed and capped. This analysis included only conditions reported to have developed after 1980. As seen in Table 54, no statistically significant increased incidence rates for health problems among recent residents were observed.

The most important result is seen in the first analysis, which shows that the increased risk for developing certain health problems occurred before the landfill was closed. The second and third analyses, however, were examined in further detail to determine if there was any implication of current landfill exposure. It was concluded that these findings do not provide evidence of ongoing chemical exposure to the landfill for four reasons. First, the results obtained are not statistically significant. Second, these analyses contain a bias, which results from the removal of persons from subsequent analyses once they have experienced the health problem for the first time. For example, the second analysis comparing current landfill residents and movers for health problems first occurring after 1981, is based on the last four years of a survival analysis, and excludes the first

Table 52: **Analysis of Health Problems First Occurring Before 1981 for Adults**

	Condition	Groups[1]	N of Events	Incidence (per 1000 person-years)	Relative Risk	p(RR)
1.	Combined Respiratory	Landfill residents	72	20.8	2.12	<.001
		Controls	36	9.9		
2.	Combined Skin	Landfill residents	68	20.1	2.26	<.001
		Controls	30	8.3		
3.	Combined Central Nervous System	Landfill residents	98	29.4	2.91	<.001
		Controls	36	10.0		
4.	Combined Mood	Landfill residents	56	16.5	1.51	.027
		Controls	38	10.6		
5.	Red, Itchy Eyes	Landfill residents	33	9.8	1.60	.045
		Controls	22	6.2		

Notes:

[1] Landfill residents are shown as series 1000-4000 and controls as series 5000-6000 in Table 43.

See other explanations on Table 44.

Table 53: **Migrator Effects: Relative Risks Before and After 1981 for Adult Non-Movers Versus Movers**

Condition		Relative Risk $\left(\frac{\text{Non-movers}}{\text{Movers}}\right)^1$	p^2
1. Combined Respiratory	(a) to 1980	.83	.400
	(b) 1981-84	2.60	.0003
2. Combined Skin	(a) to 1980	.98	.912
	(b) 1981-84	1.28	.296
3. Combined Central Nervous System	(a) to 1980	.89	.201
	(b) 1981-84	1.28	.267
4. Combined Mood	(a) to 1980	.62	.033
	(b) 1981-84	1.23	.365
5. Red, itchy eyes	(a) to 1980	1.02	.96
	(b) 1981-84	1.37	.21

Notes:

[1] Non-movers are shown as series 1000-4000 and movers are shown as series 8000 in Table 43.

[2] 2-tailed probability value. A p value of $<.01$ is required for the relative risk to be statistically significant.

Table 54: **Health Problems First Occurring After 1980 for Adult Recent Residents Versus Controls**

	Condition	Groups[1]	N of Events	Incidence (per 1000 person-years)	Relative Risk	p^2
1.	Combined Respiratory	recent landfill residents	13	18.9	.81	.25
		controls	55	23.6		
2.	Combined Skin	recent	9	12.9	.77	.25
		controls	38	16.1		
3.	Combined Central Nervous System	recent	17	24.8	1.69	.043
		controls	31	13.1		
4.	Combined Mood	recent	11	16.0	1.04	.47
		controls	28	11.9		
5.	Red, Itchy Eyes	recent	6	9.3	1.07	.88
		controls	20	8.6		

Notes:

[1] Recent landfill residents are shown as series 7000 and controls are shown as series 5000-6000 in Table 43.
[2] 2-tailed probability value. A p value of $<.01$ is required for the relative risk to be statistically significant.

nine years. Therefore, there is a large bias in the sample used to analyze health problems after 1981. Third, given the multiple analyses to which the data were subjected, it is likely that some random results may have been obtained. Finally, there is no internal consistency of results among the analyses (i.e., different health conditions appear to be identified in each analysis). These observations also apply to the findings for children presented below.

Children. When the children of landfill residents were compared to those in the control neighbourhood it was found that the relative risk increased for skin, certain central nervous system, and mood conditions before the landfill was closed. There is also evidence that before 1981 there was a difference in the incidence rates of respiratory conditions, which began to disappear after the site was closed. The increased incidence rates of red, itchy eyes had also developed before the site was closed. This was not true of five or more colds per year, a condition for which higher incidence rates developed after the site was closed.

In the second analysis, no differences were seen for respiratory, skin, or central nervous system conditions, or red, itchy eyes in a comparison of children of former and current landfill residents for health problems developing before 1981 and after that time. Borderline differences were seen in mood symptoms, as migrators reported a higher incidence than did non-movers. This same relationship was seen among the adults.

A final analysis comparing the children of recent residents and controls included only events reported to have occurred after 1980. No evidence was seen of respiratory, skin, central nervous system, or mood symptoms developing after 1980 in recent landfill residents as compared to controls. There was a trend towards an increased incidence of red, itchy eyes, but this was not statistically significant. There was also evidence of increased reports of five or more colds per year; however, increased reports of this condition occurred among the children of landfill residents after the site was closed, but not before.

C2.6 Were Increased Risks Among Landfill Area Residents Also Found for Decoy Health Problems?

An analysis of 25 health problems for adults and nine for children, which were thought to be unrelated to chemical exposure and were defined beforehand as decoy items in the questionnaire, was carried out to compare the responses of recent landfill residents and controls. The purpose of this analysis was to examine whether landfill residents were reporting higher incidences of health problems generally, rather than only those conditions that might be associated with landfill exposure. There was no indication that landfill residents were at an increased risk of developing these conditions. This is a particularly important result because it provides one of the most significant pieces of evidence found in the overall study that the particular health problems reported by landfill residents did not occur by coincidence and suggests there is some common cause for these conditions.

Adults. High risk ratios were found, however, for three conditions which were not predicted by the workers study: loss of appetite, loss of weight, and burns requiring admission to hospital. Because the first two conditions are so closely related biologically, they were combined in a Cox model analysis which turned out strongly positive. This finding might be related to chemical exposures not yet understood or it might be related to the perception of residents living near the landfill. The finding of burns requiring admission to hospital cannot be explained on the basis of exposure to the landfill.

Children. No childhood conditions, which were thought to be unrelated to landfill site exposure, were found in excess among the children of current landfill residents. These conditions included heart murmur, food allergies, frequent diarrhea, frequent constipation, earaches/ear infections, convulsions or seizures with fever, head injury with the loss of consciousness, poisoning requiring admission to hospital and accident causing bone fracture. No other child health conditions were reported in sufficient numbers in the questionnaire to allow further analyses.

C2.7 Did Landfill Area Residents Have an Increased Risk for Problems with Pregnancy or Birth Defects?

Of current landfill area residents, controls, movers, and recent residents, pregnancies were included in the analysis if they ended in or after the year of first residence in the house that qualified a woman for this study. For pregnancies among the exposed women, the controls, and movers, 1976-80 was the most prevalent period of termination, followed by 1981-84. The modal age at the beginning of pregnancy among landfill residents and controls was 25-29. The proportion of women who were 35 years or older was higher among the controls than among the landfill residents (10.4 per cent and 4.4 per cent, respectively).

No differences were seen between women living near the landfill and controls in overall presence or absence of one or more of various risk factors (i.e., medications, diseases, and workplace exposure to chemicals) during pregnancy. A trend to higher rates of diabetes among control women was noted. No differences in smoking and use of alcohol during pregnancy were noted.

The distribution of live births, stillbirths, miscarriages, and abortions did not differ significantly between groups. The trend was towards higher overall rates of problems in the controls. There was no trend toward lower birth weight among the the children of landfill mothers, and most of the low birth weight babies in both exposed and control groups were also pre-term. No unique or unusual pattern of birth defects was noted, and no increase in total birth defects was seen. Once again, the trend was toward increased birth defects in the controls. In summary, there was no evidence of an association between living near the landfill site and problems with pregnancy.

C2.8 Were There Any Other Health Problems for Which Landfill Area Residents Might Have an Increased Risk?

The purpose of these analyses was to examine four groups of health problems for adults and the health problems for children that were not derived from either the workers study or as secondary hypotheses (see page 252) but which were identified as being possibly related to chemical exposure.

Adults. No evidence for an association of living near the landfill site was seen for frequent, prolonged bruising, problems with resistance to disease or seeming to get sick easily, or for cancer, leukemia, lymphoma, or Hodgkins disease. One of four renal conditions, repeated bladder/urinary tract infections, showed a higher relative risk, but too few events were reported to allow subanalyses.

Children. The three health conditions that were not part of the initial hypothesis base but were regarded as important outcomes of the survey of children's health (because they could be associated with chemical exposures) were frequent or prolonged bruising, repeated bladder or urinary infections, and problems with resistance to disease or seeming to get sick easily. When these problems were screened for evidence of association with exposure to the landfill site, only the analysis of problems with resistance to disease or seeming to get sick easily suggested such a connection.

C2.9 Was There Evidence of Over-Reporting or Under-Reporting Recall Bias from Medical Chart Abstractions?

As has been described above, a process of abstraction from the respondents' medical charts was used to assess recall bias. The medical charts of 340 adults and 207 children were reviewed. These included all those adults and children who reported having one of the conditions designated for abstraction, as well as a small sample of adults and children who reported having none of them. The adult respondents' self-reports - concerning one condition from each of the nine conditions designated for this study - were compared with his or her medical records. Symptoms or conditions in only five of the health condition groups occurred frequently enough among children to warrant sampling.

The information found in each chart was reviewed by a nurse abstractor. When a reported condition was found in the chart, it was 'confirmed'. When a reported condition was not found in the chart, 'over-reporting' was deemed to have occurred. When a condition that had not been reported was found in the chart, 'under-reporting' was deemed to have occurred. Where the confirmation categories (i.e., confirmed, possibly confirmed, not confirmed) and methods artificially created over- or under-reporting errors, the decision was excluded from the analysis.

No evidence of bias was seen in over- or under-reporting among the adult groups. Among children, no evidence of bias was seen for over-reporting, but a trend toward an under-reporting bias was identified. Among landfill neighbourhood children, 16.5 per cent of unreported conditions were observed in the charts, (i.e., confirmed or possibly confirmed). Among controls, 22.3 per cent of unreported conditions were similarly observed.

Workshops conducted with the nurse abstractors before field work began, and after it was completed, showed that the methods of medical chart abstraction resulted in a high level of reliability, both among the abstractors and in the consistency of their individual judgments. This lends credibility to the assessment of recall bias for which these methods were developed.

C2.10 Are the Health Problems Found in Excess in Landfill Area Residents Likely to Continue?

Another objective of this study was to assess whether any health problems found in excess among the landfill residents would be likely to continue to affect their well-being. The analyses of ongoing health conditions, however, are somewhat limited because the residents study was designed primarily to examine the association between first developing health problems and exposure to the operating landfill. In spite of the limitations, analyses were conducted and the results provide insight into the current persistence and prevalence of health conditions identified in excess in landfill residents.

The health problems included in the main analysis were divided between those the respondents reported still having at the time of interview and those they reported no longer having. These data were analyzed to determine (1) whether or not the health conditions that began after people first moved into the landfill or control communities persisted to a greater extent among the landfill residents than the controls, and (2) whether the current prevalence of the health problems of interest was greater among the landfill group than the controls.

The 'persistence' question can be answered simply by examining Tables 55 and 56 (for adults and children) and comparing the proportion of residents in each study group who reported still having the condition with those who used to have it but no longer do. The persistence of the conditions for landfill area adults and children who reported still having a condition, was higher than the controls for the respiratory group. No differences in the rates of persistence were noted for skin, central nervous system, or mood conditions. Tables 57 and 58 show the results of the same analysis carried out on the individual conditions contributing to the four groups of health conditions and for red, itchy eyes. Once again, there was little evidence of a higher rate of persistence of individual conditions among the landfill area residents. The only individual condition for which increased persistence was noted for adults was for cough and phlegm and for children it was five or more colds per year.

Table 55: Current Persistence and Prevalence of Groups of Health Problems in the Main Analysis for Adults

Condition	Household Groups(a)	First Had Condition After Residence in Landfill/Control Area		Never Had Condition	Prevalence[d]		Persistence[e]	
		Still Have it	Don't Have it Now		x^2(b)	p(c)	x^2(b)	p(c)
1. Combined Respiratory	main landfill	105	44	848	30.53	$<.001$	8.62	.003
	controls	47	44	748	--	--		
	movers	37	12	420				
	recent	11	4	272				
2. Combined Skin	main landfill	113	17	867	10.50	.003	.10	.751
	controls	58	10	771	---	---		
	movers	45	10	414				
	recent	10	0	277				
3. Combined Central Nervous System	main landfill	159	11	827	29.55	$<.001$	.34	.560
	controls	64	3	772	---	---		
	movers	67	14	388				
	recent	17	1	269				
4. Combined Mood	main landfill	122	7	868	13.87	$<.001$	1.76	.185
	controls	59	7	773	---	---		
	movers	57	6	403				
	recent	11	2	274				

Notes:

(a) The households in the 'main landfill' groups are current residents who moved into the landfill area before 1980 and are defined as series 1000, 2000, 3000, and 4000 in Table 43. The 'movers' are former landfill residents who moved away from the landfill neighbourhood before 1980 and are defined as series 8000. The 'recent' group are current residents who moved into the landfill area after 1980 and are defined as series 7000.

(b) x^2 is statistical parameter called a chi square and it is used here for comparing proportions of these groups for the analyses of persistence and prevalence.

(c) p is the probability that the comparisons being made by the chi square are statistically significant.

(d) The analysis of prevalence (x^2_1) involved comparing the main landfill groups to controls for the proportion of those reporting "still have it" with the sum of those who "never had condition" and those who had the condition but "don't have it now".

(e) The analysis of persistence (x^2) involved comparing the main landfill group to controls for the proportion of those reporting "still have it" with those who had the condition but "don't have it now".

Table 56: Current Persistence And Prevelance of Groups of Health Problems in the Main Analysis for Children

Condition	Household Groups(a)	First Had Condition After Residence in Landfill/Control Area		Never Had Condition	Prevalence[d]		Persistence[e]	
		Still Have it	Don't Have it Now		x^2(b)	p(c)	x^2(b)	p(c)
1. Combined Respiratory	main landfill	81	38	855	9.82	$<$.001	9.27	.002
	controls	34	40	678	--	--		
	movers	19	21	411				
	recent	1	4	272				
2. Combined Skin	main landfill	98	45	831	4.86	.014	1.56	.212
	controls	53	16	683	---	---		
	movers	42	10	399				
	recent	7	2	166				
3. Combined Central Nervous System	main landfill	80	8	886	17.68	$<$.001	.07	.786
	controls	25	2	725	---	---		
	movers	20	4	427				
	recent	1	0	174				
4. Combined Mood	main landfill	75	4	895	7.00	.004	.21	.644
	controls	25	2	725	---	---		
	movers	33	2	416				
	recent	3	0	172				

Notes:

See explanations in Table 55.

Table 57: Current Persistence and Prevalence of Individual Health Problems for Adults

Condition	Groups(a)	First Had Condition After Residence in Landfill/ Control Area		Never Had Condition	Prevalence^{d}		Persistence^{e}	
		Still Have It	Don't Have it now		x^{2}(b)	p(c)	x^{2}(b)	p(c)
1. attacks of bronchitis	exposed controls	21 8	22 13	912 787	3.95	.046	.66	.42
2. shortness of breath	exposed controls	42 17	6 4	924 813	7.40	.007	.51	.48
3. cough and phlegm	exposed controls	60 21	28 32	884 775	13.76	.0002	11.04	.0009
4. recurrent or severe problems with scaly, dry, or itchy skin	exposed controls	57 22	1 0	905 795	10.85	$<$.001	-	-
5. frequent or severe headaches	exposed controls	99 40	7 1	808 730	17.60	.00003	-	.44
6. frequent dizziness or blurred vision	exposed controls	31 11	7 2	954 825	6.65	.0099	-	1.0
7. constant fatique, lethargy, drowsiness	exposed controls	60 19	3 3	923 815	15.89	.00007	-	.33
8. frequent feelings of anxiety or depression	exposed controls	56 18	6 5	904 803	14.72	.0001	2.17	.141
9. frequent feelings of irritability	exposed controls	46 17	2 3	935 815	9.43	.002	2.43	.118
10. red, itchy eyes	exposed controls	61 31	14 11	894 767	5.45	.0195	.907	.341

Notes:

(a) The exposed group is shown as series 1000, 2000, 3000, and 4000 and controls are shown as series 5000 and 6000 in Table 43.

See other explantions in Table 55.

Table 59 shows that for adults the central nervous system group of conditions met all these criteria. Red, itchy, eyes met the fewest criteria, while the respiratory, skin, and mood conditions met most but not all of the criteria.

The same criteria (except for consistency with the workers study) were used to assess the evidence relating to children. Age is a powerful predictor of health status and, therefore, the presence or absence of consistency between adults and children would not have been a meaningful negative result. Once again, as shown in Table 60, the strongest evidence relates to certain central nervous system conditions. The quality of evidence relating to skin conditions, mood conditions, and red, itchy eyes was intermediate. The quality of evidence relating to respiratory conditions and five or more colds per year was poor. These two conditions do not appear to be related to landfill site exposure among children.

The strength of the evidence for valid associations between living near the landfill site and health problems identified in Tables 59 and 60, however, is reduced by three factors: the high refusal rate of 32.2 per cent in the control population; differences in socioeconomic status between the landfill residents and the controls, although, even in retrospect, no better neighbourhood match could have been found in Hamilton; and, for the most part, the health problems found in excess lack medically exact descriptions and are very similiar to and even potentially interchangeable with other conditions because of the way in which the response categories of the questionnaire were designed to allow respondents to find descriptions of illness that they could relate to their specific health conditions. Offsetting these problems is the use of multiple criteria to assess the hypotheses, which were identified and evaluated according to preset rules.

In summary, the association between living near the landfill site and an increased incidence of certain central nervous system, mood, skin, and respiratory conditions among adults appears to be valid. The evidence related to red, itchy eyes is less strong but cannot be ruled out. Among children, a valid association can be argued for central nervous system, skin and mood conditions, and red, itchy eyes.

No causative agent or agents for these conditions associated with living near the landfill have been identified. Two causes may be proposed:

1) contact with a combination of airborne chemical vapours, fumes, and particulate matter emanating from the landfill site, and direct exposure of the skin to wastes in the landfill as a result of recreational activities in and around it;

2) the perception of exposure and, therefore, of risk, may have given rise to genuine health problems or symptoms on the part of landfill residents who would have become more concerned about their health than unexposed persons.

Table 59: Summary of the Results of Hypothesis Testing for Adults

Criteria for Assessing the Association	Condition				
	Resp.	Skin	Mood	Central Nervous System	Red, Itchy Eyes
1. Was the relative risk on the main analysis greater than 1.5?	Yes	Yes	Yes	Yes	Yes
Was it greater than 2.0?	No	No	No	Yes	No
2. Was the probability value for the relative risk in the main analysis less than 0.01?	Yes	Yes	Yes	Yes	Yes
Was it less than 0.001?	Yes	Yes	Yes	Yes	No
3. Were these results consistent with the workers study?	Yes	Yes	Yes	Yes	No
4. Was there a gradient of risk comparing current residents within 500 metres of the site, those farther away, and controls?	Yes	Yes	Yes	Yes	Yes
Was the gradient found primarily among long-term residents?	Yes	Yes	Yes	Yes	Yes
Was there a gradient within the landfill group only, among current long-term residents?	Yes	No	Yes	Yes	Yes
5. Was there evidence that migrator bias might explain the differences between landfill residents and controls on the main analyses?	No	No	No	No	No
6. Did the landfill site attract people who were less healthy than controls with respect to this condition?	No	No	No	No	No
7. Had the risk developed before the landfill site was closed?	Yes	Yes	Yes	Yes	Yes
8. Were increased risks among landfill residents confined to the conditions hypothesized?	No general trend to increased risks among non-hypothesized conditions, but there were a few associations.				
9. Was there any evidence of over-reporting or under-reporting recall bias on medical chart abstraction?	There was no evidence of over- or under-reporting recall bias.				

Table 60: Summary of the Results of Hypothesis Testing for Children

Criteria for Assessing the Association	Condition					
	Resp.	Skin	Mood	Central Nervous System	Red Itchy Eyes	5+ Colds
1. Was the relative risk on the main analysis greater than 1.5?	No	Yes	Yes	Yes	Yes	Yes
Was it greater than 2.0?	No	No	Yes	Yes	Yes	No
2. Was the probability value for the relative risk in the main analysis less than 0.01?	No	Yes	Yes	Yes	Yes	Yes
Was it less than 0.001?	No	Yes	Yes	Yes	Yes	No
3. Was there a gradient of risk comparing residents within 500 metres of the site, those farther away, and controls?	No	Yes	No	Yes	Yes	Yes
Was the gradient found primarily among long-term residents?	Yes	Yes	Yes	Yes	No	No
Was there a gradient within the landfill group only, among current long-term residents?	No	No	No	No	No	--
4. Was there evidence that migrator bias might explain the differences between landfill residents and controls on the main analyses?	No	No	No	No	No	No
5. Did the landfill site attract people who were less healthy than controls with respect to this condition?	No	No	No	No	No	Yes
6. Had the risk developed before the landfill site was closed?	Yes	Yes	Yes	Yes	Yes	No
7. Were increased risks among landfill residents confined to the conditions hypothesized?	No increased risks were found among non-hypothesized conditions.					
8. Was there any evidence of over-reporting or under-reporting recall bias on medical chart abstractions	A non-statistically significant trend to over-reporting of reported conditions and lower rates of under-reporting among children of landfill residents.					

The evidence from this study permits an indirect assessment of these two possible causes. Six lines of reasoning suggest that the health problems identified in excess in landfill residents were caused by exposure to landfill chemicals:

1) The consistency of symptoms between workers and residents was remarkable, considering the lack of contact between the two groups and the differing attitudes to the potential for risk expressed by their members to the study team.

2) The gradient of risk by proximity and duration of residence to the landfill site is difficult to explain on the basis of perception of risk alone. While perception of risk may be directly related to proximity to the landfill, it is difficult to believe that the relationship could be precise enough to explain the gradient by household distance from the landfill and the fact that the gradient effect involved only long-term residents among the adults.

3) The symptoms and the organ systems affected were biologically plausible on the basis of exposure to chemical substances known to be present in the landfill. It is difficult to explain how a perceptual mechanism could have caused landfill area residents to select those conditions, which could also be related to environmental exposure, without also selecting more of the decoy conditions that were included on the questionnaire, which are not related to chemical exposure. It must be acknowledged, however, that it has been impossible to show whether or not residents or workers were exposed to sufficiently high levels of landfill chemicals to cause the problems found in excess in this study.

4) If there had been a significant perceptual component to the associations found in the residents study, this should have been reflected in overreporting of health problems by landfill area residents compared to controls. No such evidence of recall bias was found when medical charts were abstracted.

5) In general, the health conditions that developed during the period when the landfill was open are disappearing at a similar rate among landfill residents and controls. Moreover, there was no evidence of greater levels of respiratory disability among the landfill residents. These findings are not characteristic of a learned illness behaviour, in which it would be expected that the conditions would last for a long period of time and become more disabling.(4)

6) Despite the fact that an informal health survey of residents was conducted by the residents themselves, and the results widely circulated through the media, the conditions found in excess in the Committee's health surveys did not confirm its findings. Had a perceptual mechanism been operating, it would have been expected that the conditions reported in this informal survey would have been confirmed. The conditions identified in the Committee's studies, however, were largely unrelated to those found in the survey the residents conducted themselves.

Four lines of reasoning, however, suggest a case for a perceptual mechanism:

1) Nuisance odours are still a frequent problem in the area and it is possible that these odours have contributed to an increased level of concern among area residents.

2) The health problems found in excess in this study can all be well explained by behavioural mechanisms. None uniquely requires chemical exposure and none is based on evidence of human tissue damage.

3) The unblinded study design may have influenced perceptual and behavioural factors affecting the experience and the recall of symptoms. Review of medical records would not necessarily be able to detect such an effect, assuming that people did in fact visit their doctors for these problems.

4) The analyses relating to migrator bias appear to demonstrate that current landfill residents tended to have higher rates of first developing the health problems after the landfill had been closed than did movers. One explanation is that living near the landfill (and, thus, perception of exposure) is the crucial determining factor, and not actual exposure to chemical vapours, fumes, and dusts. The simplest explanation for the results so obtained would be a bias in the analysis and not the perception of exposure. (See page 274)

Many of the lines of reasoning presented in favour of each causal explanation are speculative. Those that support a chemical cause, however, are based on fulfilling the preset analytic criteria for the study, which could just as easily have gone unfulfilled.

It is the opinion of the study team that chemical causation cannot be ruled out on the basis of this survey and that the factors supporting a chemical mechanism appear to be more convincing than those which would support a perceptual mechanism. Both mechanisms may have contributed to the association between living near the landfill and the health problems found in excess in this study.

This study did not produce any evidence of pregnancy problems or birth defects related to living near the landfill site. This is a very significant negative finding and one that should provide substantial reassurance. There was also no evidence of increases in major chronic diseases among landfill residents.

In Chapter 9 it is concluded that the risk of developing cancer from exposure to landfill contaminants was likely low. However, the interval between the time of first residence at the landfill (1972) and the study (1984) has not allowed an appropriate followup period. Answering this question would require following the study group of landfill residents over the next 10-20 years to assess their cancer experience through incidence and mortality registries.

References

1. C. Hertzman, J. Singer, J. Highland and M. Hayes, Residents Health Study Report for the Upper Ottawa Street Landfill Site Study, 1986.

2. Ibid., p. 66.

3. Ibid., p. 91.

4. S. Wooley, B. Blackwell, C. Winget, "A Learning Theory Model of Chronic Illness Behaviour: Theory, Treatment, and Research," Psychosomatic Medicine 40 (1978): 379-401.

PART 4

CONCLUSIONS AND RECOMMENDATIONS

CHAPTER 13

CONCLUSIONS AND RECOMMENDATIONS

TABLE OF CONTENTS

Page

A. INTRODUCTION 296

B. CHEMICAL CONTENT OF THE LANDFILL 296

- B1. APPROACHES TO EXAMINING LANDFILL CONTENTS 296
- B2. EXCAVATING THE LANDFILL 297

C. MAINTENANCE OF THE LANDFILL 298

- C1. LANDFILL COVER 298
- C2. REMEDIAL WORK 299
- C3. VEGETATION 299
- C4. LEACHATE SEEPS AND EROSION 299
- C5. MOUNDED WATER TABLE 300
- C6. NORTH SLOPE 300
- C7. LEACHATE COLLECTION 301
- C8. SECURITY 302
- C9. MAINTENANCE WORKERS 302

D. LEACHATE, SURFACE WATERS AND SEDIMENTS 302

- D1. GENERAL WATER QUALITY AND METALS 302
- D2. ORGANIC COMPOUNDS 303
- D3. MONITORING 303
- D4. DREDGING 304
- D5. RISK TO HUMAN HEALTH 305
- D6. EXPOSURE TO THE RED HILL CREEK 305
- D7. EXPOSURE OF SEWAGE WORKERS 306
- D8. CONCLUSIONS 306

E. THE DIRECTION, RATE OF FLOW AND CHEMISTRY OF GROUNDWATER 306

- E1. BACKGROUND 306
- E2. DIRECTION AND RATE OF GROUNDWATER FLOW 307
- E3. GROUNDWATER PLUME 307
- E4. CHEMICAL CONTENT OF GROUNDWATER 307
- E5. CONTAMINATION BY LEACHATE 307
- E6. HUMAN EXPOSURE 308
- E7. MONITORING 308

Page

F. CHEMICALS IN LANDFILL GAS AND SURROUNDING NEIGHBOURHOODS 309

F1. INTRODUCTION 309
F2. CHEMICALS IN LANDFILL GAS 309
F3. CHEMICALS IN NEIGHBOURHOOD AIR 309
F4. POLYCYCLIC AROMATIC HYDROCARBONS (PAHs) 309
F5. COLLECTING AND FLARING LANDFILL GAS 310

F5.1 Current Emission Levels 310
F5.2 Health Studies 311
F5.3 Gas Odour Problem 311
F5.4 Proposed Gas Collection and Flaring System 312

F6. AIR MONITORING 313

G. THE HEALTH SURVEY OF LANDFILL WORKERS 314

G1. BACKGROUND AND OBJECTIVES 314
G2. RESULTS 315
G3. FOLLOWUP STUDY 316

H. THE HEALTH SURVEY OF LANDFILL RESIDENTS 317

H1. STUDY DESIGN 317
H2. RESULTS 317

H3. POSSIBLE CAUSES OF IDENTIFIED HEALTH PROBLEMS 318

H3.1 Causation by Chemical Exposure 319
H3.2 Causation by Perception of Chemical Exposure 320

H4. FOLLOW-UP STUDY 320

H4.1 Study of Psychosocial Effects 320
H4.2 Laboratory Tests and Biological Monitoring 320
H4.3 Population Registry 321

I. OBSERVATIONS ARISING FROM THE UPPER OTTAWA STREET LANDFILL STUDY 322

A. INTRODUCTION

In this final chapter of the Report, the Committee draws its conclusions from the findings that have been reported in the previous chapters. The discussion of each set of conclusions is followed by the Committee recommendations. The conclusions and recommendations are presented in eight separate sections: chemical content of the landfill; maintenance of the landfill; leachate, surface waters and sediments; groundwater; chemicals in landfill gas and surrounding neighbourhoods; workers' health study; residents' health study; and the observations arising from the overall Study.

B. CHEMICAL CONTENT OF THE LANDFILL

B1. APPROACHES TO EXAMINING LANDFILL CONTENTS

Attempts were made to determine what was buried in the landfill by examining all relevant known documentation on disposal at the Upper Ottawa Street site and by analyzing the chemical content of core samples taken from depths of 7.6 to 24.4 metres within the landfill. A description of this work is presented in Chapter 4. Researching old records proved to be an unsatisfactory approach to reconstructing an accurate picture of what was buried in the landfill during the 30 years of its operation. Until the Ontario Ministry of the Environment's waybill system was introduced in 1977, record keeping was non-existent. Even after 1977, the records that were kept were neither precise nor informative about the amounts and types of wastes entering the site. This situation, which is likely common to other landfills in the province, is unfortunate because it precludes the use of the most reliable, inexpensive and accessible source of information as a starting point for environmental and health studies of landfill contamination.

The second approach, determining the actual wastes retrieved by drilling deep inside the garbage mound, was successful although limited in scope. The waste materials in core samples from two boreholes were found to contain high levels of aromatic hydrocarbons such as toluene, some chlorinated ethenes, large quantities of petroleum-based hydrocarbons of relatively low toxicity, and small amounts of polychlorinated biphenyls (PCBs). The small number and amount of chlorinated organics was unexpected since these highly toxic compounds have been found in large amounts at other sites. The wastes also contained polycyclic aromatic hydrocarbons (PAHs). This finding was expected because it was known that beginning in 1976 approximately 2.5 million tons of solid steel industry wastes were used as part of landfilling operations and as a cover over the site.

The Committee decided to proceed with large scale chemical analyses of contaminants that were escaping from the landfill in leachate, surface and ground waters, and air, rather than continue drilling core samples. One reason for this was that the size of the landfill prohibited obtaining sufficient core samples of wastes to provide a representative sample of the huge garbage mound. A second reason was that, in practical terms, human exposure can take place only to the chemicals migrating from the site. Numerous chemical analyses of air, leachate and water have been conducted in the three years since the core samples were examined and the results have been remarkably consistent: few compounds have been identified in any significant concentrations that were not previously detected in the initial analyses of the core samples.

B2. EXCAVATING THE LANDFILL

Measures exist for controlling the movement of chemicals from landfills. The first of these would call for removing the chemicals from the landfill and would involve excavating all or a portion of the contents of the landfill, followed by treatment and/or disposal at a more suitable location. The second type of action is to prevent migration of chemicals from the site. This would involve such steps as making the landfill cover impermeable so that leachate production is curtailed or collecting any leachate that is produced so that the potential for contamination of surface and ground waters is small. A different approach is to leave the landfill as it is but to monitor the migration of chemicals out of the site for the purpose of taking corrective action if the type or concentrations of contaminants change so that they could pose a human health or environmental risk at some future date. Monitoring consists of well-designed programs of ongoing chemical analyses that provide an early warning of changes in the types or amounts of contaminants present in leachate, air, water or soil.

Each situation involving chemical contamination is unique and calls for specifically tailored remedial measures. Excavation is a justifiable and necessary course of action in certain situations. There appears to be a good case for excavating the extremely toxic landfills along the Niagara River gorge on the basis of hydrogeological evidence that leachate is seeping from these sites through the bedrock base into the Niagara River, which has the potential of contaminating the drinking water supply of millions of people living in Ontario and New York State. The Niagara situation is particularly serious because it is known that large amounts of highly concentrated and highly toxic wastes from the chemical industry were deposited in those landfills.

By contrast, chemical analyses conducted at the Upper Ottawa Street landfill have failed to demonstrate that toxic chemicals in hazardous concentrations are migrating from it. The findings presented in this report indicate that the effects of leachate on the quality of surface or ground waters, neither of which is used for drinking water, is small and that the concern for human exposure is primarily with airborne contaminants.

In addition, there are important practical matters to consider before embarking on an excavation plan at the Upper Ottawa Street site. These include the enormous size of the landfill, the millions of tons of solid material comprising it, the extension of the base of the landfill below ground level into fractured bedrock, and the lack of a more secure destination in Ontario to which the excavated material could be transported.

In the context, then, of what is known about the chemical content of the landfill and the risk of human exposure, the question of whether excavating the site would cause more harm than good needs to be examined. Several factors suggest that excavating the entire site would be inadvisable. The analyses of leachate indicate that even if large amounts of toxic chemicals were deposited in the landfill, they are being released in low concentrations and being diluted quickly in water. In the case of heavy metals such as cadmium, nickel and lead, there is little migration because the metals appear to be contained in the domestic garbage with which they were co-disposed. Digging up the landfill could cause the dangerous release, over a relatively short time, of leachate and liquid wastes stored within the site. It is currently estimated that some 1,300 million litres of leachate are being held within the landfill.

Of greatest concern would be the almost impossible task of preventing more direct exposure of people to rapid release of high concentrations of compounds during an excavation project that would likely require many months, if not years, to complete. The concentrations of air pollutants released in such a manner would be unpredictable but could be much higher than the parts per million concentrations of volatile compounds now found in landfill gas emitting through the cover material. In addition to the release of chemicals in gas, there would also be the concern that the excavation process would generate large amounts of dust (air particulates) on which toxic substances such as PAHs are adsorbed.

RECOMMENDATION 1: The Committee recommends that excavation of the site should not be undertaken.

The Committee believes that a program to prevent chemical migration to the maximum possible extent and the careful, long-term monitoring of leachate, surface and ground waters, and landfill gas will provide a sufficient warning should conditions at the landfill change in the future and further corrective action be required. Specific recommendations on containment and monitoring are presented in subsequent sections of this chapter.

C. MAINTENANCE OF THE LANDFILL

C1. LANDFILL COVER

The condition of the landfill cover is the single most important factor in the secure containment of chemicals within the site. The purpose of the landfill cover is to prevent the production of leachate caused by the infiltration of precipitation into the garbage mound. Maintaining the landfill cover is a very long term problem. Over the years the integrity of a cover can be expected to improve as thick vegetation takes root and provided that regular repairs are made to trouble spots. As a result leachate production and migration should decline.

C2. REMEDIAL WORK

A description of the remedial work undertaken by the Hamilton-Wentworth Regional Engineering Department during and after the closure of the site in 1980-1981 is given in Chapter 2 of this Report. Over one million dollars have been spent on major remedial efforts, including covering the landfill with a thick intermediate cover of steel wastes, a thin top layer of clay-like material, hydroseeding of grass and planting of trees; constructing an erosion control wall on the north slope of the mound; and constructing a system of pipes and drains for collecting leachate and discharging it into a sanitary sewer via a central collection manhole.

The Committee has carefully observed the impact of this work over the past four years, and believes that sufficient time has passed to make an accurate assessment of the adequacy of these measures.

C3. VEGETATION

After an initial slow start, most areas of the landfill mound are now covered with vegetation, which is necessary to protect the underlying cover and to promote the evaporation of precipitation. With the exception of some unvegetated patches requiring further seeding efforts, the cover on the top and east and west slopes of the landfill appears to be mostly intact and well vegetated. Permeability measurements of the intermediate cover layer of steel wastes and clay cap indicate that these materials may be fairly impermeable if erosion is prevented.

RECOMMENDATION 2: The Committee recommends that spring and late summer seeding be undertaken each year until the remaining exposed surfaces of the landfill cover are vegetated.

C4. LEACHATE SEEPS AND EROSION

There are noticeable problems, however, with numerous areas of leachate seepage on the lower south slope along Stone Church Road and on the north side above and below the retaining wall along Red Hill Creek. The leachate springs, which are caused by the elevated water table within the garbage mound, are usually located in erosion gullies. Further, there are some fairly large areas on the south side that do not appear to be eroded but are nevertheless saturated with black, oily leachate.

The problem of erosion gullies, which are more than 60 cm deep in places, is particularly serious. Exposed garbage can be observed on the north side of the site because of its extremely steep slope. Evidence of some erosion is evident elsewhere but it is less severe and likely caused by the displacement of decaying garbage beneath the cover. Leachate seeping out of the erosion gullies flows down the erosion wall into the Red Hill creek. Leachate is also discharging from within the mound beneath this wall. Persistent repair and maintenance will be required to control the problems of leachate springs and erosion gullies.

RECOMMENDATION 3: The Committee recommends that the following steps be undertaken each spring and fall to make repairs to the landfill cover:

a) erosion gullies should be lined with a geotextile (i.e., synthetic material used for outdoor construction) and packed with gravel or stone to preserve a surface drainage system;

b) leachate seeps should be connected by french drains to the existing collection pipes on the west, south, and east slopes of the landfill;

c) careful inspection of all parts of the cover should be conducted and repair work should be done until a decline in leachate production and migration is observed and then this spring and fall schedule can be re-examined.

C5. MOUNDED WATER TABLE

During the groundwater study discussed in Chapter 6 of this Report it was determined that the infiltration of precipitation into the landfill over many years caused mounding of the water table to a present height of about seven metres above the surrounding ground level. This level did not decrease between 1979 and 1984 and it is not possible to predict if or when this will occur. Until the water mound recedes below ground level, leachate springs will continue to be a problem. This situation calls for continual maintenance. Changes in the height of the water table will indicate whether the landfill cover is effective in curtailing leachate production.

RECOMMENDATION 4: The Committee recommends that the height of the mounded water table be measured annually from boreholes on the northeast corner of the landfill (Sites 15 and 16 on Figure 6 and described in Appendix 2) where previous measurements were taken. Two monitoring wells are currently located at these sites and can be used for this purpose if they are in working condition. If not, new installations will be required.

C6. NORTH SLOPE

The condition of the cover on the north slope presents two different problems. The first is that its uneven and eroded surface permits the direct infiltration of precipitation, thereby preventing a reduction in the production of leachate, a decrease in the level of the mounded water table and elimination of the leachate springs. The erosion wall has acted as a stabilizing barrier between the base of the landfill and the creek but it was not designed to prevent erosion of the upper slope or to stop leachate seepage.

The second, and potentially more serious, problem is the continuing discharge of leachate directly into the Red Hill Creek. The chemical findings presented in Chapter 5 suggest no significant difference in the chemistry of the creek upstream or downstream of the landfill at the present time. If the situation were to change in the future and the landfill becomes a major source of creek pollution, corrective measures would then be required. The available options might include extensive work such as diverting the creek bed farther north away from the base of the landfill for leachate collection or partially excavating the north slope in order to eliminate the steep grade and permit the construction of a leachate collection system.

RECOMMENDATION 5: The Committee recommends examining the feasibility of collecting the leachate that is flowing down the surface of the north slope into the creek and disposing of it in the sanitary sewer.

C7. LEACHATE COLLECTION

The evidence indicates that the leachate collection system is not operating effectively. Despite the fact that the leachate collection system was installed on the south side of the landfill, numerous leachate seeps can still be observed. Leachate springs, of course, only account for a small amount of the total volume of leachate migrating from the site. The groundwater study estimated that 83.6 million litres of leachate per year are flowing out of the landfill. Since 1981 the volume of leachate collected in two pump units on the east side of the landfill is recorded to be in the order of 1,500 to 3,800 litres daily, or 547,500 to 1.4 million litres annually, which is only a small fraction of the estimated total volume of leachate moving out of the landfill. From this information it can be concluded that most of the leachate is bypassing the collection system and likely passing into the bedrock below the site.

The Committee has been informed that plans are being made to install a device to measure the volume of leachate being collected from the west and south sides of the landfill. The continued recording of the volume of leachate collected by the pumping systems would provide information on future trends in production of leachate, on the effective functioning of the leachate collection system and on the actual amount of leachate being discharged into the sanitary sewer.

RECOMMENDATION 6: The Committee recommends that measurements be made and that records be kept of the volume of leachate being collected by the separate systems installed on the west and south sides and to the east of the site.

C8. SECURITY

There are two aspects of landfill maintenance that are not directly related to the condition of the cover. The first is the security in place to prevent public access to the site. This currently consists of fencing around the west, south and east sides of the site. The concern is that the unfenced north side of the site, where leachate springs are entering the Red Hill Creek, is a temptation for children. This is the only remaining area of the landfill where there is easy entry for the public.

RECOMMENDATION 7: The Committee recommends that access to the landfill and creek on the north side be restricted by fencing.

C9. MAINTENANCE WORKERS

The second aspect deals with safety precautions for workers who are making repairs onsite, particularly in the closed space of the leachate collection manhole. Workers have refused to enter the manhole until they have received assurance that maximum protection is being afforded by the equipment and protective clothing provided.

RECOMMENDATION 8: The Committee recommends that maintenance workers be protected from skin contact with leachate. The chemical findings on landfill gas indicate that it is unnecessary to wear a protective mask unless work is being done directly on the gas vents themselves. Masks should be provided, however, for those who wish to wear them when working in areas of lower gas concentration. The Committee recommends the use of a self-breathing apparatus and high quality protective clothing for workers who enter the underground collection manhole.

D. LEACHATE, SURFACE WATERS AND SEDIMENTS

D1. GENERAL WATER QUALITY AND METALS

The impact of landfill leachate on the water quality of the Red Hill Creek, primarily with respect to heavy metals and broad water quality parameters, has been tracked by the Ontario Ministry of the Environment since 1976. The Committee focused on the analyses of organic compounds in a regular monitoring program, which began in 1983. Sufficient data have been collected to demonstrate the extent to which the landfill is contributing to pollution in the Red Hill Creek. These findings are discussed in detail in Chapter 5.

The water quality of leachate as measured by standard parameters such as chloride, hardness and nitrogen-containing compounds, is obviously poor. The effect of leachate on the general water quality of the Red Hill Creek can be observed immediately downstream of the site but the effect is not large. The quality of the creek water by the time it flows farther downstream to Albion Falls is similar to that upstream of the landfill.

Leachate contains of a number of metals, with aluminum and iron in highest concentrations. In the Red Hill Creek, however, the levels of heavy metals are extremely low and are no higher downstream than upstream of the landfill.

D2. ORGANIC COMPOUNDS

The organic compounds in leachate, which are found in concentrations of low ppm or less, are similar to those detected in the core samples of landfill wastes but are found in greater variety because of the more comprehensive analytical methods used for leachate testing. The organics in leachate include the volatile aromatic hydrocarbons (such as benzene and toluene), chlorinated hydrocarbons (dichloromethane, dichlorobenzenes), phthalates, tetrahydrofuran and 1,4-dioxane. The organics in greatest numbers and highest concentrations were detected in leachate in the collection manhole. Polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs) were also detected in leachate. Although the leachate samples used in the analyses may not contain all chemicals found in the landfill, these findings suggest the site was not used for the disposal of large volumes of organic chemical wastes.

D3. MONITORING

A monitoring plan for leachate, surface water and sediments is required for two purposes. The first is to provide sampling points for chemical analyses that serve to provide an early warning of possible increases in the levels of toxic chemicals. The leachate collection manhole, where more types of chemicals in higher amounts are present than at any other sampling site, is one important monitoring point. Monitoring data will also provide an indication of the relative contribution of the landfill to the creek, in terms of its chemical content, before it reaches the site and after it flows past.

RECOMMENDATION 9: The Committee recommends that samples of leachate from the leachate collection manhole (see Site 32 in Figure 6 and Appendix 2) and from two leachate springs on the north slope of the landfill be collected twice annually, during the spring and late summer. Once work has been completed to eliminate surface leachate springs on the north side, a permanent sampling station should be established there for the collected leachate. Samples should be analyzed using the best available methods for quantitative analyses of trace organic compounds. At the present time this is the GC-MS method. The compounds detected in the Committee's work could serve as the target list for these analyses. Analysis should also be capable of detecting "priority pollutants" not detected in the Committee's work.

There are fewer detectable organic compounds in the Red Hill Creek than in leachate and the concentrations of those detected are lower. It can be concluded that the impact of leachate is small because the levels of organics are not significantly higher downstream than upstream of the landfill. So long as leachate is being produced by the landfill and discharged into the Red Hill Creek, ongoing monitoring of the organic compounds in the creek is required.

RECOMMENDATION 10: The Committee recommends that samples of the Red Hill Creek water upstream and downstream from the landfill (see Sites 2 and 22 in Figure 6 and Appendix 2) be collected twice a year, during the spring and late summer, and analyzed using the methods outlined above for leachate.

The detection of PAHs and PCBs in leachate led to an investigation of these chemicals in the creek sediments. Because of their low solubility, they would be expected to be found in sediments rather than in the creek water. With the exception of methylphenanthrene, PAH concentrations in sediments were actually higher upstream of the landfill than downstream. In contrast, the levels of PCBs in sediment were somewhat higher immediately downstream than upstream from the landfill. At no site did the concentrations of PCBs exceed 1 ppm.

RECOMMENDATION 11: The Committee recommends that samples of sediments from the Red Hill Creek upstream and downstream from the landfill (Sites 2 and 22) be collected once a year during the late summer and analyzed for polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs) using the best available methods for quantitative trace analysis of these compounds.

RECOMMENDATION 12: The Committee recommends that this monitoring work on leachate, surface water and sediments be conducted as described above for five years. If, at that time, the results indicate a sufficient decrease in the concentrations and numbers of compounds, or if no change is detected, less frequent sampling and analysis could be considered.

RECOMMENDATION 13: The Committee recommends that the monitoring data be reviewed by the appropriate persons in the city and regional governments, by the Ontario Ministry of the Environment and by at least one external consultant. The results should be made public each year.

D4. DREDGING

The Committee decided against recommending the dredging of the Red Hill Creek to remove contaminated sediments because the current risk to health is low.

In addition, within a short period of time following dredging, the sediments would again be contaminated from both the upstream and landfill sources of PAHs and PCBs.

D5. RISK TO HUMAN HEALTH

The impact of the landfill on the quality of water in the Red Hill Creek would appear to be small in relation to other sources of pollution. This does not mean, however, that the creek bed bordering the landfill is safe for public access nor does it guarantee that the situation will not become worse over time should larger amounts of toxic compounds be discharged into the creek in leachate.

The risk to human health from exposure to landfill chemicals in surface water and sediments is discussed in Chapter 9 of this Report. The conclusion is drawn that the current risk is not significant for two reasons:. 1) there is limited opportunity for human contact with these chemicals and 2) the current levels of contamination are small. With respect to leachate it is concluded that while there is limited opportunity for exposure, the leachate does contain appreciable amounts of toxic chemicals.

These conclusions are reassuring but they only apply if the nature and concentrations of chemicals in the future remain low. Therefore, the Committee believes it is essential to conduct chemical monitoring. It is also important to take all necessary steps to ensure that persons are not needlessly exposed to landfill contaminants and other sources of pollution in the Red Hill Creek.

D6. EXPOSURE TO THE RED HILL CREEK

It is particularly important that children be kept off the landfill and away from the north slope bordering the creek. The new housing being built south of Limeridge Road and towards Red Hill Creek suggests that greater numbers of children will have regular access to the creek.

RECOMMENDATION 14: The Committee recommends that in the unlikely event that fish are being caught in the Red Hill Creek, appropriate public warnings should be posted advising against their consumption. The reason for this is that many chemicals are concentrated in fish to levels hundreds or thousands of times higher than those of the same chemicals in the water in which the fish live.

RECOMMENDATION 15: The Committee recommends that swimming or playing be prohibited in the Red Hill Creek.

D7. EXPOSURE OF SEWAGE WORKERS

The amount of leachate being discharged from the landfill into the sanitary sewer is estimated to be in the order of 1,500 litres to 3,800 litres daily. It is estimated that the leachate is greatly diluted by the estimated 227 million to 379 million litres of sewage that reaches the treatment plant per day. Therefore, the chemicals in leachate are not adding significantly to the chemical content of sewage to which treatment plant workers are being exposed. In addition, the chemicals in the leachate are typical of those that are likely to be present in Hamilton's industrial sewage generally. Therefore, it would not be possible to define any specific exposure or health risk to sewage treatment plant workers from the Upper Ottawa Street landfill.

D8. CONCLUSIONS

In assessing whether the monitoring of, and prevention of exposure to, leachate, surface waters and sediments is adequate to deal with the problem, several aspects need to be examined. The landfill contamination of the Red Hill Creek is not severe. This conclusion is supported by chemical evidence collected over several years, taking into account seasonal variations. The second is the long-term expectation that the volume of leachate discharging into the creek should decrease as the landfill cover becomes increasingly more effective and leachate production is therefore curtailed. The third consideration is that there may be chemicals in the landfill that were buried in intact barrels and could be released if the barrels corrode or break open. At this point, there is no evidence of the presence of such chemicals but monitoring is necessary. If future monitoring shows higher concentrations of known toxic or carcinogenic compounds or of previously unidentified chemicals, other solutions will have to be examined.

E. THE DIRECTION, RATE OF FLOW AND CHEMISTRY OF GROUNDWATER

E1. BACKGROUND

An extensive groundwater investigation, believed to be the largest study of its kind in Canada, was conducted at the Upper Ottawa Street Landfill site. This study was needed because very little research had been done by hydrogeologists on the flow of groundwater in the kind of complex fractured bedrock upon which the landfill sits.

The Ontario Ministry of the Environment confirmed from records that no one in the area was drinking water from household wells. There were initial concerns, however, that the groundwater might be severely contaminated by leachate; that it might in future discharge at the face of Albion Falls; and that the contaminated plume might be moving in several directons. Findings on the hydrogeology of groundwater are discussed in Chapter 6 and the chemistry of groundwater is discussed in Chapter 7 of this Report.

E2. DIRECTION AND RATE OF GROUNDWATER FLOW

The study confirmed that the general groundwater flow pattern is from west to east, following the downward slope of the regional water table towards Albion Falls.

It was found that the pattern of fractures in the bedrock and its hydrogeological properties (such as hydraulic conductivity, hydraulic gradient and porosity) cause the groundwater to move both east and downward. It is concluded that by the time the groundwater reaches the escarpment it is flowing deep within the rock under the base of Albion Falls and does not surface until it reaches Lake Ontario. The velocity of the groundwater flow is estimated to be in the range of 1.5 to 2.0 metres per day.

E3. GROUNDWATER PLUME

Based on estimates of the rate of leachate production, which is in the order of 83.6 million litres per year, and the velocity of groundwater flow, it is likely that a "plume" of leachate now exists in groundwater over the nine kilometre distance between the landfill and Lake Ontario. It would appear that it would take only a few years of leachate production to develop such a plume (of approximately 270 million litres). The issue of whether this groundwater plume is a significant environmental problem can only be examined within the context of its chemical content.

E4. CHEMICAL CONTENT OF GROUNDWATER

Analyses of both inorganic and organic compounds were carried out by four laboratories on numerous samples of leachate and groundwater. The most serious obstacle encountered in the chemical analyses was the impossibility in most cases of determining which groundwaters were polluted by the landfill. This situation resulted from an unanticipated problem. It turned out that groundwaters in the region are contaminated by naturally occurring chemical substances in the bituminous, hydrocarbon-rich, bedrock with the result that even groundwater which has not come into contact with leachate contains appreciable quantities of organic compounds, especially the volatile aromatic hydrocarbons.

The organic chemicals, which were detected in groundwaters, whether their source is leachate or bedrock or both, are essentially the same compounds as those found in leachate, surface waters and sediment, but their concentrations are lower. These include aromatic hydrocarbons and phenolic compounds. In addition, dichloromethane and dichlorobenzene were detected.

E5. CONTAMINATION BY LEACHATE

The conclusion of the chemical findings is that the most serious groundwater contaminationn occurs within 100 metres of the landfill. Beyond this distance, even in the direction of the groundwater flow to the east, landfill contamination becomes indistinguishable from background levels. It is also concluded that the groundwater plume discharging into Lake Ontario is unlikely to have a measurable impact because its chemical content does not appear to be greatly different from that of the natural groundwater.

E6. HUMAN EXPOSURE

Residents have expressed concern that they might be exposed to leachate contaminated groundwater. This is unlikely for several reasons. People in the area are not using wells since drinking water is supplied by city water lines. The emergence of groundwater to the ground surface is unlikely because the groundwater is flowing at some depth. The closest the groundwater comes to the surface to the west of the landfill where housing is located, is seven to eight metres. On the other hand, groundwater immediately to the east is less than one metre below ground surface.

RECOMMENDATION 16: The Committee recommends that no excavation work be undertaken in the low lying area immediately east of the landfill, and that no housing be constructed there because this area is in the path of leachate migration.

E7. MONITORING

There does not appear to be a public health hazard or a significant environmental risk associated with landfill contamination of groundwater at the present time. There are, however, two reasons that support ongoing monitoring of groundwaters. Many organic compounds whose identity has not been established are present in the groundwaters. As mentioned previously, there may be chemicals which were disposed of in the landfill in containers that have not yet ruptured. If this situation exists, it could pose a future hazard. Monitoring will provide assurance that the major compounds of concern in groundwater are properly identified and that their movement through groundwater is adequately followed.

RECOMMENDATION 17: The Committee recommends the installation of four additional multilevel piezometers for the purpose of long-term monitoring of groundwater quality. The piezometers should be multiple sampling devices and be installed specifically at sites 7, 9, 12 and 22 (shown in Figure 7 as Waterloo Research Institute sampling points). These sites are close to the perimeter of the landfill where contamination has been confirmed. Details on the design and installation of these piezometers and a sampling protocol are contained in Waterloo Research Institute's final report to the Committee. For the next five years, the analyses of groundwater samples should be carried out twice a year using the best available approach to quantitative analysis of organic compounds, which is currently GC-MS.

F. CHEMICALS IN LANDFILL GAS AND SURROUNDING NEIGHBOURHOODS

F1. INTRODUCTION

Air contaminated by landfill gas is the most likely route of exposure for people who live near the landfill. Landfill gas was sampled from vents that extend into the garbage mound. Ambient air was sampled at upwind and downwind locations in neighbourhoods surrounding the landfill and also in other areas of Hamilton for comparison. A discussion of the methods and results of landfill gas and air testing is contained in Chapter 8.

F2. CHEMICALS IN LANDFILL GAS

The volatile compounds detected in the testing of landfill gas were, for the most part, the same as those found in leachate, surface and ground waters. The chemicals in highest concentrations in the gas were the aromatic hydrocarbons, while the chlorinated hydrocarbons (dichloromethane, 1,1-dichloroethane and 1,2-dichloroethene) were found in appreciable amounts at a number of sites. In general, however, relatively low concentrations (i.e., low ppm range) of most compounds were observed in what is essentially undiluted landfill gas. Analyses established that the gas is diluted by air by as much as 1,000 times at a distance of only one metre from the gas vents.

F3. CHEMICALS IN NEIGHBOURHOOD AIR

A monitoring program extending over three years was carried out for volatile organic compounds in air in the neighbourhoods surrounding the landfill and at control locations elsewhere in Hamilton. Only a few compounds, primarily the aromatic hydrocarbons (benzene, toluene, xylenes) were detected, and these occurred at low ppb levels. The monitoring results indicate no clear trend in the concentration of compounds over time and show that levels of compounds are as high or higher in upwind and control sites than those observed downwind from the landfill. These findings show that the contribution of chemicals from the landfill is small compared to the contribution from motor vehicles and other non-landfill sources of air pollution. Concentrations are similar to those observed in other cities.

F4. POLYCYCLIC AROMATIC HYDROCARBONS (PAHs)

In addition to the analysis of landfill gas and ambient air discussed above, a separate testing program for polycyclic aromatic hydrocarbons (PAHs) in air particulates was conducted. Because several million tons of steel wastes containing PAHs were deposited at the site, there was concern about possible levels of current exposure. The concentrations of PAHs in landfill gas were found to be low and there were no significant differences in the levels of representative

PAHs among upwind, downwind and offsite control locations. This suggests that the landfill makes a negligible contribution to the PAH content of air in the vicinity of the site as compared to the contribution from non-landfill sources, especially motor traffic. These findings on PAHs are consistent with mutagenicity assays carried out on landfill gas and air particulates, which showed that the landfill does contain some mutagenic chemicals, but not in high concentrations.

F5. COLLECTING AND FLARING LANDFILL GAS

The Committee, in its 1983 Interim Report, recommended that a gas collection and flaring system be installed at the site. This work was to have been carried out in three stages. The first was to be the construction of a pilot plant, the operation of which would provide information about the optimum conditions for combustion, and on the possible formation of combustion products that might be harmful to human health. A great deal of additional work has since been carried out by the Committee. This has included the regular monitoring over a three year period of ambient air in neighbourhoods near the site, a study of landfill gas dispersion based on meteorological data, and health studies of both workers and residents. The earlier recommendation on gas collection and flaring must be re-evaluated in the context of all that is now known about the site and its possible effects on human health.

F5.1 Current Emission Levels

There is strong evidence that current emissions of target compounds from the landfill are producing concentrations of these compounds that are not measurably higher than the background. In other words, the contribution of the landfill to concentrations of these compounds in neighbourhoods surrounding the landfill is small compared to that coming from other sources, such as motor traffic and industry. The results of the gas dispersion studies are consistent with these findings. On the other hand, the question of the presence of certain unidentified compounds of landfill origin in ambient air in concentrations that are harmful to human health is obviously relevant. Given the high dilution resulting from gas dispersion, however, one would expect that if such compounds were present they would have been found in high concentrations in the landfill vent gases. Since compounds would have to be fairly volatile and, therefore, of no great chemical complexity, they would probably have been identified. Therefore, while we cannot totally eliminate this possibility, we consider it to be unlikely.

An additional concern relates to concentrations of the identified compounds. There seems to be good evidence that on a time-average basis their levels are well below those considered to be dangerous to human health. There could occasionally be air currents, however, that result in contamination plumes in which concentrations are many times greater than average.

It is also important to recognize that conditions within the landfill are continuously changing. Such evidence as there is suggests that both the amount of landfill gas being emitted and the concentrations of toxic contaminants are no higher today than when the Interim Report was written some three years ago.

There is no guarantee, however, that this will continue. It is even possible that at some future time the emissions of toxic substances from the landfill could be much greater than at present and become a significant hazard to human health. This concern, however, must be put into perspective. The toxic compound identified in highest concentration at the present time is benzene whose measured concentration in the residential areas at the time of sampling was one to four parts per billion. This would need to increase several hundred-fold before the currently accepted ambient air quality standard in Ontario of 950 parts per billion would be exceeded. If, in the future, there were to be a dramatic increase in the amounts of chemicals being released to the air from the landfill (an event which we judge to be unlikely) the situation could, of course, change.

F5.2 Health Studies

The health studies, which will be discussed in Sections G and H of this chapter, have provided evidence that before 1980 (when the landfill was in operation) there was an association between living near the landfill and an increase in certain 'central nervous system' (i.e., headaches, lethargy), 'mood' (i.e., anxiety, depression), 'skin,' and 'respiratory' conditions. Furthermore, the weight of the evidence appears to favour chemical exposure, rather than a perception or concern by residents that their health is at risk because they lived near the landfill, as the likely cause of this relationship.

The health conditions identified, however, appear to relate primarily to past rather than to current exposure since health problems that developed when the landfill was open are disappearing at similar rates for those living near the landfill (exposed population) and those living at a distance (controls).

F5.3 Gas Odour Problem

One of the arguments presented for collecting and burning the landfill gas in the Interim Report was the release of strong odours from the landfill. It is explained in Chapter 8 that while odours coming from the landfill cannot be interpreted as evidence of the presence of toxic chemicals, the mercaptans normally produced in landfills create an exceedingly unpleasant and even nauseating smell. Gas company records for the years 1976-1984 were examined to see if the pattern of complaints about gas odours made by the residents living near the landfill could be linked to the site. Both natural gas and landfill gas have a mercaptan odour, therefore, the examination was focused on complaints of gas odours for which the company servicemen could find no cause. It is interesting to note that such complaints of gas odours by households in the landfill neighbourhoods have marginally increased since 1980, which indicates that closing and covering the landfill has not solved the odour problem (see Appendix 1).

In addition to being a public nuisance, the odour problem in the neighbourhoods around the landfill is a constant reminder to area residents of their possible exposure to toxic and carcinogenic chemicals. The accelerated pace of residential and commercial development that has been evident recently in close proximity to the landfill further suggests that the magnitude of public concern will increase over time if efforts are not made to address the odour problem. The Committee has concluded that the need to eliminate the odour problem alone provides sufficient reason for burning off the landfill gas.

It should also be pointed out that landfill gas is being flared at at least five sites in Ontario for the purpose of controlling odour and methane migration. In the Toronto area, at the Bear Road and Brock Road landfills, landfill gas is flared primarily to control odours. A new active gas collection and flaring system is being constructed at the Brock Road site at a cost of $4.5 million to replace the existing system of flaring the gas as it emits passively through pipes installed in the site. In addition, at the Keele Valley landfill an active system is being installed at an estimated cost of $5 million for controlled burning and in an attempt to market untreated methane as a fuel source.

In summary, the scientific evidence obtained during the Committee's investigation suggests that the possibility of persons being exposed to dangerous levels of landfill airborne contaminants is small. On the other hand, the odour of the landfill is a nuisance to neighbouring residents that is not tolerated in other regions of Ontario. As long as there is a detectable odour, the level of concern of area residents for their health and safety will not diminish, no matter how small the actual risk might be.

F5.4 Proposed Gas Collection and Flaring System

This proposed system is called an 'active collection system' because it uses a pumping system to collect landfill gas for flaring. The alternative collection system is referred to as a 'passive system'. The passive system uses positive pressure naturally existing under the landfill cover to transmit the gas for flaring.

It is the Committee's opinion that a passive system is not suitable for the Upper Ottawa Street landfill because of: a) the likelihood that a large portion of the gas would continue to escape from the landfill through the cover and b) the need for a controlled flow of landfill gas to sustain a high temperature flame in the flare chamber.

This work should be implemented in three stages, the first of which would consist of a continuous pumping and flaring test to be carried out for at least one month on three test wells to be installed on the Stone Church Road side of the site. It is necessary to verify the findings of the preliminary tests done for the Committee by Conestoga Rovers Associates Ltd. (CRA) and to provide data for designing a permanent gas control system. The recommended first phase pilot study must provide further evaluation of the byproducts of flaring landfill gas and of the estimated rates of landfill gas production and recovery.

The second stage would involve the construction of a permanent installation along the Stone Church Road side of the landfill. Based on CRA's preliminary design concept, which might be modified in the light of findings in the pilot study, it is proposed that this installation consist of a network of wells connected through lateral pipes leading to a vacuum pumping system and a flare plant, which would be located in a vacant service building on the west side of the landfill.

The estimated cost of installing an active gas control system on the Stone Church Road side of the landfill, as described, was estimated in 1983 to be about $600,000, with an additional annual operation and maintenance cost of approximately $50,000.

The third stage in the installation of a gas control system involves constructing a system, similar to the one described above, on the Red Hill Creek side of the landfill. Modifications to the proposed system would be required because of the extremely steep slopes on the north side of the site.

An active gas control system on the Red Hill Creek side is estimated to cost aproximately $500,000. This system would also require additional annual operation and maintenance expenditures.

CRA has recommended that the potential for energy utilization from the landfill gas flaring system be reviewed for feasibility. It should be recognized, however, that any such energy utilization must not compromise the basic design criteria of the gas system to control landfill gas emissions.

RECOMMENDATION 18: The Committee recommends that an active landfill gas collection and flaring system be installed at the Upper Ottawa Street landfill and that the first phase of this work should begin as soon as possible.

F6. AIR MONITORING

Until a gas collection and flaring system is constructed at the landfill, an extensive program of air monitoring in neighbourhoods surrounding the site is needed to show whether the toxic or carcinogenic compounds being released in landfill gas are continuing to be diluted to safe (i.e., background) levels offsite. After consulting with the Committee, the Region implemented a planned three year program of air monitoring beginning in the fall of 1985. The results obtained so far from this work are similar to the Committee's findings.

Once the gas collection and flaring system has been installed, the monitoring program recommended below should be reviewed and modified.

RECOMMENDATION 19: The Committee recommends a monitoring program consisting of a minimum of six air tests annually each involving the analysis of at least four samples of landfill gas from the existing test well (site 1 in Figure 12 and Appendix 5) and other gas probes or boreholes on the landfill and at least three samples of ambient air from sites upwind and downwind of the landfill and on the site itself. Samples of landfill gas should be collected in air bags, and samples of ambient air by sorbent tubes until better sampling techniques are developed. Samples should be analyzed using the best

available methods for quantitative analyses of trace organic compounds, which at the present time is the GC-MS method. The compounds detected in the Committee's work should serve as the target list for these analyses. Analysis should also be capable of detecting 'priority pollutants' not detected in the Committee's work.

RECOMMENDATION 20: The Committee recommends that an air monitoring program be continued until there is evidence that the production of gas within the landfill has declined significantly.

RECOMMENDATION 21: The Committee recommends that the air monitoring data be reviewed by appropriate persons in the city and regional governments, by the Ontario Ministry of the Environment and by at least one external consultant. The results should be made public each year.

G. THE HEALTH SURVEY OF LANDFILL WORKERS

G1. BACKGROUND AND OBJECTIVES

The workers' health study was designed to describe the current and past health problems of landfill workers and to generate hypotheses concerning the impact of the landfill on health that could be tested in a survey of the health of residents. While the workers' study gave important clues for design of the subsequent residents' study, it was not possible to design a health study of workers that could prove definitively that landfill exposure was a cause of workers' health problems. The first reason for this is that little was known about the types and concentrations of chemicals to which workers were exposed and this made it impossible to select target health problems. In addition, only a small number of the workers who came into contact with the landfill actually worked on a regular basis on the garbage mound itself. A complete discussion of the workers health study is in Chapter 11.

The workers study was done before the residents study because the workers had longer and more direct exposure to landfill chemicals than did residents, making it likely that health problems could be observed more readily among workers. If similar health problems were reported by both workers and residents, this would increase the possibility that landfill exposure was the cause.

Approximately 200 landfill workers were contacted for the study as was a control group who were similar in most respects to the landfill workers except that their outdoor employment did not involve working at or near a landfill. The health reports of landfill workers were analyzed and compared with those of the control group.

During the first stage of the survey experienced interviewers administered specifically designed health questionnaires in the respondents' homes. The second stage was a medical chart abstraction study in which the respondents gave permission for nurse abstractors to examine their medical records kept by family doctors. The purpose of this study was to investigate recall bias by comparing questionnaire responses of landfill workers and controls with medical records according to defined categories of confirmation and non-confirmation. Over- or under-reporting of health problems in the survey is referred to as a recall bias.

G2. RESULTS

1) The main conclusion of the workers health survey is that there are three groups of health problems that appear to be associated with working at the landfill: chronic bronchitis, daily cough, combined respiratory problems; certain central nervous system symptoms such as headaches, dizziness, lethargy and balance problems; and mood disorders such as anxiety, depression, trouble sleeping, irritability and restlessness.

2) Also identified were health problems having a weaker association with working at the landfill than the three groups of health problems identified above: difficulty breathing, skin rash, combined skin problems, and muscle weakness in arms and legs.

3) The landfill workers were most likely to have first developed these health problems between 1970 and 1980, which coincides with the periods of increasing and maximum waste disposal at the site.

4) Landfill workers tended to develop these health problems in the first five years after beginning to work at the landfill, which implies that if the landfill is the cause of these problems longer term exposure was not required.

5) Most of these health problems, which developed after first exposure to the landfill, have persisted and remain more prevalent among landfill workers than controls. This issue is addressed in the following discussion of the residents health study.

6) Analysis of the overall pattern of mortality for 21 landfill workers who died between 1965 and 1983 indicates that there was no significant difference in the mortality risk for landfill workers at the time the study was conducted, although this analysis has limited statistical power.

7) The medical chart abstraction study demonstrated that landfill workers did not over-report their health problems compared to controls.

8) No statistically significant differences were found between landfill workers and the control group for 107 other health problems listed in the questionnaire. These include high blood pressure, stroke, diabetes, gall bladder disease (which have no known chemical related cause) and other problems such as stomach ulcer, gastrointestinal, reproductive, kidney and bladder conditions and diseases of the blood (which can be caused by chemical exposures).

G3. FOLLOW-UP STUDY

These findings of the study strongly suggest an association between working at the landfill and certain health problems. The results of the study, however, cannot be used independently to draw conclusions about causation because, as discussed in Chapters 10 and 11, the strategic objective was to conduct an hypothesis generating study to provide target health problems to be investigated in the residents study. The study team anticipated that similar results from both studies would strengthen the evidence that landfill exposure was the cause of certain health problems.

In a discussion of the health study of residents (see Section H) the conclusion is reached that the cause of the identified health problems in both workers and residents was likely related to exposure to landfill chemicals, although a non-chemical cause such as perception of risk leading to illness cannot be entirely ruled out.

In light of these findings, the most important issue is what, if anything, should now be done about workers health. The first factor to consider is that the identified health problems are not considered to be severe in terms of disability at home or in the workplace. In fact, the most reassuring finding of the workers study is that the types of severe illness known to be caused by chemical exposure, such as certain diseases of the kidney, bladder, stomach, liver and blood, were not observed in landfill workers.

If the health problems identified had been of a different type and amenable to specific treatment, a medical program might be required. The identified health problems, however, are common to the general population and are treated routinely by family physicians. If there were an indication from the workers study that there might be rare diseases or damage to certain organs from chemical exposure that could only be seen through clinical diagnostic testing, such clinical studies could be carried out. None of the findings of the workers health study, however, suggests the occurrence of specific chemically-related diseases that could be detected clinically.

One aspect of the workers health survey that cannot be ignored is the fact that workers may have been exposed to unknown levels of carcinogenic chemicals at the landfill. No increased incidence of cancer was observed in landfill workers but given the long latency period for development of cancer, final conclusions cannot be reached for at least two decades. Efforts were made to assess the possible cancer risk associated with past landfill exposure but it proved to be an impossible task because of the lack of information about the types and amounts of waste materials deposited at the site (see page 187). Recommendation 22 pertains to the monitoring of any possible change in cancer risk for landfill workers (page 322).

H. THE HEALTH SURVEY OF LANDFILL RESIDENTS

H1. STUDY DESIGN

The design of the health study of residents was similar to the workers' study. The first part of the survey involved the administration of questionnaires by experienced interviewers in the respondent's home. The questionnaire was very much like the one used for workers but expanded to include questions on children and maternal-child health. In most cases the respondent was the female head-of-household who answered questions on behalf of all members of her family. The questionnaire survey was followed by a medical chart abstraction study of family physician records. A detailed discussion of the results of the residents' health survey is contained in Chapter 12.

Over 1,700 households were contacted to participate in the study. Households in the landfill neighbourhood were classified into six separate groups: by distance from the landfill (within 500 metres or 500 to 750 metres), by length of residency (for fewer than three years or more than three years between 1976-1980), former landfill residents who moved elsewhere in the region, and 'recent' residents who moved into the landfill area after the site was closed in 1980. The seventh and eighth groups consisted of comparison households selected from a west Hamilton mountain neighbourhood remote from the landfill.

The design of the residents study was focused on the associations found in the workers study between certain health conditions and working at or near the landfill. The residents study encountered two problems that could reduce the strength of its findings: a high refusal rate among the controls (32.2 per cent versus 18.8 per cent for the landfill residents group) and a moderate difference in socioeconomic status between controls and landfill residents (controls have higher incomes, more education and a higher proportion of white collar jobs than landfill residents) although, in retrospect, no better neighbourhood match could be found in Hamilton.

H2. RESULTS

1) A positive association is indicated between landfill residence and certain respiratory, skin, central nervous system (headaches, dizziness, fatigue) and mood (anxiety, depression, irritability) health problems in adult landfill residents. These findings are consistent with the workers study. Similar results were also obtained for children living near the landfill, with the difference that respiratory conditions were not statistically significant but red, itchy eyes were.

2) It was observed that adults with longer term residence in houses located closer to the landfill had a higher incidence of these health problems than did adults living in similar households located farther away from the site. This provides strong evidence in support of an association between the observed health problems and chemical exposure.

3) Decoy questions were included in the questionnaire to examine whether landfill residents would report a higher rate of all health problems compared to the controls and not just conditions that could be related to landfill exposure. There was no evidence of residents living near the landfill developing health conditions that are unrelated to chemical exposure.

4) The assessment of recall bias in the medical chart abstraction study found no evidence from doctors' records that landfill residents were over-reporting their health problems on the questionnaire or under-reporting (i.e., evidence of health problems found in medical charts but not reported in the questionnaire) as compared to the controls.

5) The excess health problems occurring in residents of the landfill area developed while the landfill was open and large amounts of wastes were being deposited. The health conditions reported on the questionnaire as first developing before 1981, have been disappearing at a similar rate for residents and controls. There is no convincing evidence that exposure to the landfill after it was closed and covered in 1980-81 has led to health problems among area residents.

6) No pregnancy problems, including stillbirths, miscarriages, low birth weight or birth defects, were observed in residents living near the landfill as compared to controls. These problems are sensitive indicators that have been found in other studies of landfill populations, therefore, it is reassuring that these problems were not seen here.

7) There was no evidence of increases in major chronic diseases among residents living near the landfill.

H3. POSSIBLE CAUSES OF IDENTIFIED HEALTH PROBLEMS

H3.1 Causation by Chemical Exposure

While the cause of the observed increased incidence of health conditions appears to be associated with living near the landfill (or working at or near the site), it has not been possible to identify the causative agent or agents. The health problems could be caused either by actual chemical exposure or by the belief of people that living near the landfill is a health risk. This concern over the potential harmful effects of exposure to the landfill (i.e., perception of exposure) could have given rise to genuine health problems or symptoms of stress.

The results from the residents health study suggest six lines of reasoning that favour chemical exposure as the cause of the observed excess of some health problems in landfill workers and residents:

a) The fact that essentially the same health problems were identified by workers and residents cannot be easily explained by perceptual factors, especially considering the lack of contact between the two groups and the different perceptions of risk expressed by them.

b) The observation that there were more health problems among residents who have lived closer to the landfill for longer periods of time than those who lived farther away, or were resident for a shorter period, seems too coincidental to be explained by the perception of risk by persons living near the landfill.

c) The health problems identified in workers and residents are ones that could have been caused by chemical exposure (biologically plausible). If perception were the cause it is likely that a variety of other health problems not related to chemical exposure would also have been identified.

d) The health conditions observed in workers and residents were not those found in a well-publicized informal health survey conducted by the Residents Association before the Committee's health surveys were initiated. If the residents had been influenced by their perceptions of exposure, it is likely that there would be some overlap between the findings.

e) The assessment of recall bias in the medical chart abstraction study did not find evidence of over-reporting of health problems on the questionnaire by landfill workers or residents as compared to controls.

f) The health problems that first developed in workers and residents when the landfill was open seem to be disappearing at the same rate as those being experienced by the control groups. In addition, landfill residents do not report disability from respiratory complaints. These findings are not characteristic of learned illness behaviour.

H3.2 Causation by Perception of Chemical Exposure

There are four lines of reasoning, however, that appear to suggest a case for a 'perception of exposure' mechanism:

a) Nuisance odours are still a frequent problem in the area and it is possible that these odours have contributed to an increased level of concern among area residents.

b) The specific health problems found in excess among landfill workers and residents (i.e., respiratory, skin, certain central nervous system, mood) can all be explained by behavioural mechanisms. None uniquely requires chemical exposure or is based on evidence of human tissue damage.

c) Perceptual factors could have been influenced by the unblinded study design (i.e., interviewers knew who were landfill workers and residents and controls and, therefore, could have treated the study groups differently). In addition, the medical chart abstraction study could simply have confirmed that landfill workers and residents sought medical help for perceived problems.

d) Some subanalyses comparing patterns of health problem reports between former landfill residents (migrators) and current area residents can be more easily explained by perception of exposure to chemicals emitting from the landfill than by exposure itself. There are, however, alternate explanations to be considered and these are outlined in Chapter 12 of this Report.

It is the opinion of the Committee that the weight of the evidence is stronger in favour of a chemical exposure cause for the excess health problems identified in both landfill workers and residents.

H4. FOLLOW-UP STUDY

After reaching these conclusions about the health of people who work and live near the landfill, the Committee considered whether or not there is a need for additional followup studies. In the previous discussion of the results of the workers health survey it was concluded that the establishment of a registry to assess the possible cancer risk associated with past exposure to the landfill was the only followup study that could be justified. The Committee believes that this conclusion also applies for the same reasons to the residents.

H4.1 Study of Psychosocial Effects

The Committee considered conducting a study of the possible negative psychological and social effects associated with living near the landfill. The first consideration is that the landfill has been closed and covered for five years. The health surveys found an excess incidence of health problems, which appears to be associated with working and living near the landfill prior to 1980-81. There is also evidence that these health problems are disappearing at the same rate in landfill area residents and controls. There is no basis, therefore, for assuming that a pattern of continued ill health exists or that the current health status of people living near the landfill could be further defined or explained by a study of psychosocial effects.

A second consideration is that the Committee is unable to identify any direct benefits for residents that would result from such a study. The Committee believes that an investigation of the psychosocial effects in the Upper Ottawa Street landfill neighbourhood would be primarily of academic interest. It is of the opinion that there is insufficient justification for recommending that a large-scale psychosocial study be conducted as a followup to the Committee's investigation.

H4.2 Laboratory Tests and Biological Monitoring

There is nothing in the results to indicate that clinical examination, laboratory tests or biological monitoring (see page 196 for definitions of these terms) would be useful in the further examination of the health of the landfill workers or area residents. While the Committee's studies have shown that certain health problems occurred more frequently in landfill workers and residents than in controls; these conditions are common in the general population, constituting a nuisance to those affected, but not representing medically severe or life threatening conditions. Further, while on balance we favour the hypothesis that these conditions were caused by chemical exposure, our studies did not provide any insight as to what compounds may have been involved. Similarly, there is no evidence from the chemical analysis of air or water, that particular chemicals currently occur in high enough concentrations to cause measurable health effects. Thus, neither of the two conditions (known exposure to a particular toxin or toxins, or detection of disease that could have been caused by exposure to known toxic chemicals) which would justify biological monitoring for particular chemical agents are fulfilled.

The Committee was prepared to recommend physical examinations, laboratory tests or biological tests for landfill workers or residents only if such procedures would help to determine whether or not the health of these groups had been adversely affected. It is evident from the earlier sections of this Report that such testing cannot be expected to help to answer this question. Of particular importance are the lack of any indication that there is significant current exposure and the failure of the questionnaire survey to identify diseases tht might have been caused by chemical exposure. Further, it appears that the health problems diagnosable by objective tests that may have existed in the landfill population are disappearing.

In the absence of clear indications for their use, laboratory screening tests are not productive and may even give rise to confusion. Invasive tests, such as fatty tissue biopsies, are painful and may result in complications. These facts make it unlikely that the control and exposed groups would consent to invasive testing (or perhaps even to physical examination). The facts do not justify such procedures.

H4.3 Population Registry

The possibility that the health survey would detect an increased incidence of cancer was even smaller for residents than workers because of the recent exposure for most people living in the area and the latency period of several decades for cancers to develop. No increased incidence of cancer was observed in the health surveys of workers or residents.

In view of the fact that the period of the study was too short to permit seeing an increased incidence of cancer (even if people were exposed) and that there is a lack of evidence about whether or not workers and residents were exposed to significant levels of cancer causing chemicals, the Committee recommends the establishment of a registry of landfill workers and residents who were identified for the health surveys. This recommendation in no way suggests that the Committee has any evidence suggesting that workers and residents are more likely than the general population to develop cancer as a result of their working or living near the landfill. The proposed registry would require no active participation from landfill workers or residents because the process involves linking records of reports of cancer with the Ontario Cancer Treatment and Research Foundation.

RECOMMENDATION 22: The Committee recommends setting up a registry of landfill workers and area residents who were identified for the health surveys for the purpose of following the incidence of cancer in these populations. The registry should be set up under the auspices of the Ontario Cancer Treatment and Research Foundation.

I. OBSERVATIONS ARISING FROM THE UPPER OTTAWA STREET LANDFILL STUDY

During the course of its extensive investigation, the Committee has learned many lessons that might be helpful to other investigators. The experiences of the Committee are documented throughout this Report, and some of the important observations made by the Committee are summarized here.

Although there are similarities among landfill sites, and problems of chemical exposure generally, no two situations are the same. Among the unique characteristics of each landfill are the use and operation of the site including the nature of the chemicals deposited, the hydrogeological setting, the location of surface water, and most importantly, the proximity of people working and living near the site. Given the different features of each site, it is unrealistic to assume that one method of investigation can be applied with equal effectiveness to all landfills.

A significant investigation of the possible health and environmental impacts associated with a landfill site requires a large commitment of time and money. The methods currently available to carry out chemical analyses and epidemiological investigations cannot usually produce quick results. In the case of air, water and other samples, testing over a period of months or years is required to characterize chemical contamination. Likewise, the design of epidemiological studies, the administration of health survey questionnaires and the final step of data analysis usually require several years to complete. Depending on the size of the study groups, such studies cost in the order of hundreds of thousands of dollars. The Committee would caution the public and those conducting the research against the expectation that any results other than of a preliminary nature can be obtained within a short time frame. The Committee's investigation of the Upper Ottawa Street landfill site has required five years to complete at a cost of almost two million dollars.

In any event, the Committee did not discover evidence for either significant current exposure to toxic landfill chemicals or serious disease associated with landfill exposure. A great deal of the Committee's time, effort, and funds were devoted to eliminating various potentially serious possibilities. The resources required to provide an adequate basis for these essentially negative conclusions are at least as great as those that would have been required to establish that a serious hazard did exist had that been the case.

Two aspects of carrying out health surveys are particularly important. The first is the identification of the exposed landfill population and a suitable control group. A large amount of effort went into successfully identifying current and former landfill workers and residents. The issue of fully identifying the study population is critical because in these situations, persons who developed health problems may move away from the area before the study begins or may be unable to participate directly in the study because of ill health. Effort also went into finding a comparable group using census data and matching by factors associated with housing type and price. This approach, however, was not entirely successful although in retrospect, the best matched control neighbourhood available in Hamilton was selected. It is the Committee's view that a demographic census of the study population and potentially appropriate control groups needs to be carried out in order to provide the basis for a good matching process. A second prominent aspect is that of response rates, which is a problem common to all types of survey research. It is clear that special eforts must be made at every stage of a health survey to maximize questionnaire completion rates, particularly among the control population, which, in most cases, has no vested interest in participating.

The Committee believes that the most important factor in undertaking environmental analysis, especially the analyses of trace organic chemicals, is the choice of experienced analysts. Because the commercial development of this field is relatively new in Canada, the choice of laboratories is limited and professional standards, which would assist prospective clients in selecting a laboratory, have not yet been fully developed.

A final observation has to do with the siting of landfill operations and similar facilities. It is the opinion of the Committee that constructing a new landfill site near a population or allowing residential or business development to expand within close proximity to an existing site will inevitably lead to concern that people are being exposed to dangerous levels of toxic chemicals, regardless of any evidence that might exist to the contrary. It is a particularly complex issue in view of the fact tht it is not always possible for new landfill sites to be located in areas of low population densities or for old sites to be kept isolated from development..

LIST OF FIGURES

Figures Page

1 Location of the Upper Ottawa Street Landfill 4

2 Location of Landfill and Surrounding Neighbourhood 5

3 Historical Development of the Site 1954 - 1978 12

4 Location of Households by Distance From the Landfill 21

5 Growth of Population in the Vicinity of the Landfill 22

6 Location of Sampling Sites for Chemical Analyses 56

7 Location of the University of Waterloo Research Institute Sampling Points and Piezometers 103

8 Regional Geological Setting of the Landfill 104

9 Schematic Vertical Geological Sections 105

10 Water Table Map 109

11 Vertical Cross Section Showing Hydraulic Head 111

12 Location of Sampling Sites for Landfill Gases and Air in Surrounding Neighbourhoods 144

13 Annual Ground Level Concentrations ($\mu g/m^3$) due to Unit Emission Rate (lg/s) from Source - Total Landfill Area 165

14 Summer Ground Level Concentrations ($\mu g/m^3$) due to Unit Emission Rate (lg/s) from Source - Total Landfill Area 166

LIST OF TABLES IN TEXT

Tables		Page
1	Composition of Steel Wastes in Top Cover of Landfill	54
2	GC-MS Analyses of Polycyclic Aromatic Hydrocarbons (PAHs) in Core Samples	59
3	Electron Capture-Gas Chromatography Analyses of Polychlorinated Biphenyls (PCBs) in Core Samples	60
4	Quantitative GC-MS Analyses of Polycyclic Aromatic Hydrocarbons (PAHs) in Steel Wastes	62
5	Metals Analyses of Leachate	73
6	Metals Analyses of Surface Waters	75
7	GC-MS Analyses of Leachate	80
8	GC-MS Analyses of Polycyclic Aromatic Hydrocarbons (PAHs) in Leachate	82
9	EC-GC Analysis of Polychlorinated Biphenyls (PCBs) in Leachate	83
10	EC-GC Analyses of Leachate for Chloro-Organic Pesticides	84
11	GC-MS Monitoring of Surface Waters	86
12	Results of Polycyclic Aromatic Hydrocarbons (PAHs) in Surface Waters	87
13	EC-GC Analysis of Surface Waters for Chloro-Organic Pesticides	89
14	GC-MS Analysis of Sediments for Polycyclic Aromatic Hydrocarbons (PAHs)	90
15	EC-GC Analysis of Red Hill Creek and Leachate Sediments for Polychlorinated Biphenyls (PCBs)	92
16	Metals Analyses of Groundwaters	123

Table		Page
17	Results of GC-MS Analysis of Organics in Groundwaters	125
18	EC-GC Analysis of Groundwaters for Chloro-Organic Pesticides	127
19	Chemical Content of Background Groundwaters	129
20	Comparison of Chemical Content of Background Groundwaters, Downgradient Groundwaters and Leachate	131
21	Calculated Maximum Flux of Selected Contaminants Entering Groundwater at the Landfill Site	133
22	Analyses of the Main Constituents in Landfill Gas	146
23	GC-MS Analyses of Landfill Gas for Volatile Organics	147
24	A Comparison of Landfill Gas Samples from the Same Sites at Different Times	149
25	GC-MS Analyses of Air at Various Distances from Gas Vents on the Landfill	150
26	GC-MS Analyses of Landfill Gas for Polycyclic Aromatic Hydrocarbons (PAHs)	152
27	Summary of Quantitative Results for the TAGA Analyses	155
28	GC-MS Analyses of Air in the Neighbourhood Close to the Landfill	157
29	Variations in GC-MS Air Survey Results on Successive Days	159
30	GC-MS Air Survey Results for Sampling over a Three Year Period	160
31	Analysis of Ambient Air for Polycyclic Aromatic Hydrocarbons (PAHs)	162
32	Estimated Emission Rates and Atmospheric Dispersion of Major Landfill-Sourced Contaminants	167
33	Concentrations of Trace Organics in Pre- and Post-Flaring Landfill Gas	172

Table		Page
34	Known or Suspected Carcinogens Detected in Surface Water, Leachate or Sediment at Concentrations Above Drinking Water Criteria	184
35	Possible Target Sites and Effects of Chemicals Identified at Elevated Levels in Samples Taken in or Near Upper Ottawa Street Landfill Site	200
36	The Risk of Developing Health Conditons Associated with Working at or Near the Upper Ottawa Street Landfill Site	222
37	The Years of Highest Risk (for Landfill Workers as Compared to Controls) for Developing Health Conditions (in Terms of Events per 1,000 Person Years)	226
38	The Period of Highest Risk (for Landfill Workers as Compared to Controls) by Number of Years Since First Exposure	228
39	The Risk Associated with Gradient of Exposure for Persons Who Worked Onsite, and Adjacent to the Landfill, and for Controls	229
40	Relative Prevalence of Selected Health Conditions at Time of Interview	231
41	A Comparison of Medical Chart Abstraction Results for Over-Reporting by Selected Health Conditions	234
42	An Evaluation of the Association of Specific Problems and Working at or Near the Upper Ottawa Street Landfill	237
43	Initial Classification of Households Adjacent to the Landfill Site	246
44	Risk of Developing Health Problems Associated with Living Near the Landfill Site for Adults	259
45	Risk of Developing Health Problems Associated with Living Near the Landfill Site for Children	262
46	Risk Gradient by General Proximity of Residence to Landfill Site: Short and Long-term Adult Residents	266
47	Risk Gradient by Continuous Distance Variable for Adults	267

Table		Page
48	Risk Gradient by General Proximity of Residence to Landfill Site: Long-term Adult Residents Only	268
49	Risk Gradient by General Proximity of Residence to Landfill Site: Short and Long-term Residents' Children	270
50	Risk Gradient by Continuous Distance Variable for Children	271
51	Risk Gradient by General Proximity of Residence to Landfill Site: Long-term Residents' Children Only	272
52	Analysis of Health Problems First Occurring Before 1981 for Adults	275
53	Migrator Effects: Relative Risks Before and After 1981 For Adult Non-Movers Versus Movers	276
54	Health Problems First Occurring After 1980 for Adult Recent Residents Versus Controls	277
55	Current Persistence and Prevalence of Groups of Health Problems in the Main Analysis for Adults	282
56	Current Persistence and Prevalence of Groups of Health Problems in the Main Analysis for Children	283
57	Current Persistence and Prevalence of Individual Health Problems for Adults	284
58	Current Persistence and Prevalence of Individual Health Problems for Children	285
59	Summary of the Results of Hypothesis Testing for Adults	288
60	Summary of the Results of Hypothesis Testing for Children	289

LIST OF APPENDICES

APPENDIX 1
Miscellaneous Studies

APPENDIX 2

Description of Sampling Sites For Chemical Analyses Shown in Figure 6

APPENDIX 3
Table:

1 Water Quality and Inorganic Analyses of Leachate

2 Monitoring of Surface Waters for Water Quality and Inorganic Parameters

3 GC-MS Analyses of Leachate

4 Target Compounds Not Detected in GC-MS Analyses of Leachate

5 Non-Targeted Compounds in GC-MS Monitoring of Leachate Collection Manhole

6 GC-MS Monitoring of Surface Waters

7 Target Compounds Not Detected in GC-MS Monitoring of Surface Waters

APPENDIX 4
Table:

1 Water Quality and Inorganic Analyses of Groundwaters Near to the Landfill

2 Water Quality and Inorganic Analyses of Groundwater Distant from the Landfill

3 GC-MS Analyses of Groundwaters Near to the Landfill

4 GC-MS Analyses of Groundwaters Distant from the Landfill

APPENDIX 5

Description of Sampling Sites for Air Analyses Shown in Figure 12

APPENDIX 6

Membership of the Advisory Health Group

APPENDIX 7

Referees Engaged to Review Health Studies

APPENDIX 8

Studies Prepared for The Upper Ottawa Street Landfill Site Study Committee

APPENDIX 9

Bibliographical Notes on Committee Members

APPENDIX 1

MISCELLANEOUS STUDIES

The Committee has undertaken studies in four additional areas: geophysical surveys, examination of animals, a survey of absentee rates due to illness for children attending a neighbourhood school, and an examination of gas company records.

Geophysical Studies

The Committee attempted to address the suggestion that the landfill may be a 'time bomb'. Specifically, are there barrels of hazardous wastes buried in the dump that will one day corrode and release their contents into the landfill and the outside environment?

Conflicting information was received about the number of intact barrels that might be buried in the landfill. Some reports suggested that barrels were stacked in piles and covered carefully. Others claimed that most barrels were crushed by bulldozers at the working face of the dump.

Waterloo Geophysics Ltd. was asked to determine if geophysical techniques could be used to detect steel barrels within the landfill and if geophysical methods could locate concentrations of toxic wastes (other than those in barrels) within the landfill mound. The company carried out preliminary investigations employing ground-imaging radar, magnetometers, and electromagnetic detectors.(1)

Ground-imaging radar was demonstrated to have potential for locating barrels only at a depth of less than 10 feet - too limited a penetration to be useful. Magnetometer instruments also did not provide useful information because of the impossibility of distinguishing between barrels and other metal objects such as car bodies. Electromagnetic techniques, including an EM-15 metal detector and EM-31 and EM-16R conductivity instruments, were tried but also failed to provide information because of shallow penetration capability and the uniform conductivity/contamination levels over the landfill. The overall results of this study suggest that geophysical techniques are unlikely to provide an answer to the question of whether barrels are buried in the landfill.

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(1) Waterloo Geophysics Inc., A Preliminary Geophysical Study at the Upper Ottawa Street Landfill Site, September 1982.

Small-Animal Study

A small-animal study was undertaken for the purpose of obtaining information on whether the health of animals exposed to the landfill has been affected and if tissue residue analysis might identify chemicals in the landfill that were not being detected in the other analytical work. This study was intended to provide clues for the health studies of workers and residents. Limitations of this study included the small number of animals and a lack of knowledge concerning the exposure of the animals to other possible sources of pollution.

Two racoons, two squirrels and one rabbit were trapped on or near the landfill. A gross necropsy and histopathology examination of the animals were done at the Ontario Veterinary College, University of Guelph. No abnormalities or other findings of significance were observed. Tissue residues were analyzed at the Pesticide Residue Laboratory in Guelph and it was concluded that the trace amounts of chemicals detected in the samples are characteristic of background levels normally found in animal tissues. This suggests that these animals did not come into direct contact with significant amounts of toxic chemicals from the landfill.(2)

School Absenteeism

A particularly sensitive concern to area residents is the close proximity of schools to the landfill. This issue was addressed by investigating whether children attending Blessed Kateri Tekakawitha Separate School were absent from school more often because of illness than were children attending two schools on the west mountain and in Stoney Creek. These two schools were selected for comparison because of similar student population size, age of school and similar neighbourhoods in which the schools are located.

With the permission of the Hamilton-Wentworth Roman Catholic Separate School Board, student attendance records were reviewed at the three schools for kindergarten through grade eight for the years 1978 to 1981 inclusive. The data were tabulated by computer and the results are calculated as a ratio of illness days to term days. This ratio provides a standardized measure of absence.

	1978	1979	1980	1981	1978-80 Average
West Mountain	.0573	.0456	.0394	.0439	.0466
Blessed Kateri	.0425	.0421	.0390	.0451	.0421
Stoney Creek	.0382	.0333	.0364	.0353	.0385

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(2) I.K. Barker, Reports on Pathology and Pesticide Residue Analysis of Animals Trapped On and Near the Upper Ottawa Street Landfill, December 1982.

These results indicate that there is little difference among average absenteeism rates for students attending these three schools. The west mountain school appears to have the highest rate of absenteeism, followed by Blessed Kateri and then the school in Stoney Creek.

Gas Company Records

The Committee obtained from Union Gas the records of all service calls to the homes of residents living in the study area. These records consist of the service orders prepared by the Union Gas office and the subsequent report filled out by the serviceman after the customer's complaint had been investigated. The records covered the years 1976 - 1984. Data from these records were compiled and examined to. see if any significant conclusions could be found based on the hypothesis that a pattern of customer complaints about gas odours could be linked to gas coming from the Upper Ottawa Street landfill.

It is evident from the results that the percentage of complaints about gas odours for which no cause was found has not decreased since the landfill was closed and covered. In fact, the complaints have marginally increased (an annual average of 22 per cent from 1977-1980, and 28 per cent from 1981-1984).

	Total # of complaints serviced by Union Gas	# of complaints with no cause found	per cent
1976	40	13	33%
1977	59	12	20%
1978	65	11	17%
1979	37	10	27%
1980	42	10	24%
1981	61	22	36%
1982	43	8	19%
1983	74	17	23%
1984	43	15	35%

Location (by Compass Direction) of Union Gas Customer Complaints in Relatio to Landfill Site 1976 - 1984*

NW	N	NNW	NNE	E	W	NE	ENE	WNW	SW	SE	S
29	27	14	14	11	10	5	3	2	1	1	1
24.6%	22.9%	11.9%	11.9%	9.3%	8.5%	4.2%	2.5%	1.7%	0.8%	0.8%	0.8%

*Complaints of gas odours for which Union Gas Servicemen could find no cause.

Monthly Distribution of Union Gas Customer Complaints 1976-1984*

	'76	'77	'78	'79	'80	'81	'82	'83	'84	monthly total
Jan.	-	3	1	1	-	-	-	-	3	8
Feb.	2	-	1	-	1	1	-	2	-	7
Mar.	1	-	2	-	1	3	1	2	4	14
Apr.	-	2	-	1	2	1	1	2	1	10
May	4	-	1	-	1	-	3	-	-	9
June	-	-	-	3	-	2	-	2	2	9
July	1	-	1	2	-	2	-	-	2	8
Aug.	1	3	-	1	1	-	-	-	1	7
Sept.	2	1	-	-	-	2	-	2	1	8
Oct.	1	1	2	1	1	2	1	3	1	13
Nov.	1	1	2	-	1	5	1	1	-	12
Dec.	-	1	1	1	2	4	1	3	-	13
annual total	13	12	11	10	10	22	8	17	15	

* Complaints of gas odours for which Union Gas Servicemen could find no cause.

Annual Number of Union Gas Customer Complaints for Three Specific Neighbourhoods 1976-1984*

	1976	1977	1978	1979	1980	1981	1982	1983	1984
Quinndale	2	8	5	7	5	7	2	9	3
Lisgar	4	3	4	-	1	5	3	4	4
Berrisfield	3	-	-	1	4	3	1	1	2

*Complaints of gas odours for which Union Gas Servicemen could find no cause.

Location (by Zone) of Total Number of Union Gas Customer Complaints 1976-1984*

Zone 1 (within 500 m of the landfill)	28	(23.7%)
Border of Zone 1 & Zone 2	10	(8.5%)
Zone 2 (within 500 m to 750 m of the landfill)	51	(43.2%)
Just Outside Zone 2	29	(24.6%)
TOTAL	118	(100.0%)

*Complaints of gas odours for which Union Gas Servicemen could find no cause.
See Zones 1 and 2 in Figure 4.

APPENDIX 2

LOCATION OF SAMPLING SITES FOR CHEMICAL ANALYSES

(Shown in Figure 6)

Site Number	Description
1.	Groundwaters from Waterloo Research Institute (WRI) borehole (UW20 in Figure 7), located more than 500 metres west of the landfill. Samples taken from two piezometers: UW 20-4 at a depth of 34.6 metres and UW 20-5 at 40.1 metres deep.
2.	Surface water and sediment from Red Hill Creek upstream west of the landfill.
3.	Leachate on south bank of Red Hill Creek below city works yard parking lot.
4.	Groundwaters from WRI borehole (UW10-1 in Figure 7) located 200 metres west of the landfill at a depth of 10 metres.
5.	Sediment from Red Hill Creek at storm sewer outlet.
6.	Leachate from borehole standpipe located on the northwest corner of the landfill at a depth of 22.5 metres. Also the location of WRI borehole (UW26-1 in Figure 7) at a depth of 30.8 metres.
7.	Groundwater from WRI borehole (UW8-5 in Figure 7) located opposite landfill on north side of Red Hill Creek at a depth of 25.9 metres.
8.	Sediment from Red Hill Creek at base of landfill.
9.	Leachate and sediment from north slope of landfill flowing into Red Hill Creek.
10.	Groundwater from WRI borehole (UW7-1 in Figure 7) located on north side of Red Hill Creek at depth of 6.4 metres.
11.	Leachate from north slope of landfill (UW 29 in Figure 7)
12.	Leachate and sediment from north slope of landfill.

13. Groundwater from WRI borehole (UW 22-2 in Figure 7) located on north side of Red Hill Creek at depth of 48.5 metres.

14. Groundwater from WRI borehole (UW 16-3 in Figure 7) located 400 metres north of the landfill at a depth of 31.7 metres.

15. Leachate from WRI borehole (UW 28-2 in Figure 7) located on northeast corner of landfill at a depth of 20 meters.

16. Leachate from borehole standpipe located on northeast corner of the landfill at a depth of 32 metres.

17. Leachate from north slope of landfill.

18. Leachate from base of north slope of landfill in the Red Hill Creek.

19. Leachate from former pond on east side of landfill that collected leachate and was called the 'blackhole' by area residents.

20. Groundwater from WRI borehole (UW 6 in Figure 7) located on north side of Red Hill Creek east of the landfill. Samples taken from two piezometers: UW 6-1 at a depth of 3.7 metres and UW 6-5 at a depth of 27.9 metres.

21. Groundwaters from WRI borehole (UW 27-6 in Figure 7) located on the north side of Red Hill Creek east of the landfill and drilled at an angle to a depth of 12.2 metres below the landfill.

22. Surface water and sediment from Red Hill Creek downstream of landfill to the east.

23. Groundwater from WRI borehole (UW3 in Figure 7) located on south side of Red Hill Creek 300 metres east of the landfill. Samples taken from two piezometers: UW 3-2 at a depth of 8.4 metres and UW 3-4 at a depth of 12.6 metres.

24. Groundwater from a borehole standpipe located east of the landfill at a depth of 9.8 metres and from WRI borehole (UW 1-4 in Figure 7) in same location at a depth of 8.1 metres.

25. Groundwater from WRI borehole (UW19 in Figure 7) located 700 metres east of the landfill near the pond and Albion Falls. Samples taken from two piezometers: UW19-1 at a depth of 7.2 metres and UW 19-4 at a depth of 16.2 metres.

26. Surface water and sediment from Red Hill Creek at Albion Falls located downstream to the east of the landfill.

27. Groundwater from WRI borehole (UW21-3 in Figure 7) located at 325 metres east of the landfill at a depth of 23.5 metres.

28. Groundwater from WRI borehole (UW 14 in Figure 7) located 250 metres southeast of the landfill. Samples taken from two piezometers: UW 14-1 at a depth of 5.9 metres and UW 14-4 at a depth of 24.1 metres.

29. Groundwater from borehole located southeast of the landfill at a depth of 15.5 metres.

30. Groundwater from WRI borehole (UW 12-3 in Figure 7) located 50 metres to the east of the landfill at a depth of 21 metres.

31. Sediment from open ditch on south side of landfill east of the leachate collection manhole.

32. Surface water and leachate from leachate collection manhole located on southeast corner of landfill, which collects leachate and surface runoff from collection system and open ditches on east and south sides of landfill.

33. Groundwater from WRI borehole (UW24-4 in Figure 7) located offsite immediately south of the landfill at a depth of 15.6 metres.

34. Leachate and sediment from open ditch on south side of landfill west of the leachate collection manhole.

35. Leachate from south slope of landfill.

36. Leachate from borehole on south end of landfill, which was not operational and contained a thick, black, oily substance.

37. Groundwater from WRI borehole (UW17 in Figure 7) located immediately west of the landfill. Samples taken from two piezometers: UW 17-1 at a depth of 4.6 metres and UW 17-5 at a depth of 26.8 metres.

38. Groundwater from WRI borehole (UW5-2 in Figure 7) located 300 metres west of the landfill at a depth of 10.5 metres.

39. Groundwater from WRI borehole (UW 23-3 in Figure 7) located east of the landfill at a depth of 18.9 metres.

40. Groundwater from WRI borehole (UW 2-4 in Figure 7) located east of the landfill at a depth of 18.1 metres.

41. Groundwater from WRI borehole (UW 15-1 in Figure 7 located west of the landfill at a depth of 6.1 metres.

APPENDIX 3 - Table 1: Water Quality and Inorganic Analyses of Leachate
parts per million (unless otherwise shown)

	Site 6[a]	Site 11[b]	Site 13[b]	Site 17[c]	Site 19[d]	Site 35[e]	Drinking Water Criteria[f]
pH[g]	7.6	7.7	7.9	7.7	8.2	8.4	6.5 to 8.5
BOD (biological oxygen demand)	130			3.5	107.4	248	
COD (chemical oxygen demand)	4,000			35	776	4,008	
conductivity[h]	25,400	13,100	25,900	1,930	12,150	17,750	
TOC (total organic carbon)							5.0
DOC (dissolved organic carbon)		294	4,600				
hardness[i]		1,680	401.5				80-100
calcium		88	19				
magnesium		355	86				
sodium		2,120	4,700				below 20
potassium		408	135				
chloride	2,860	3,183	4,362	203	2,733	3,410	250
alkalinity[i]	11,500	3,543	9,130	195	2,640	4,297	30-500
sulfate		40	130				500
fluoride		1.3	6.6				1.2 (natural 2.4)
nitrite, as N	0.20	0.03	0.41	0.52	0.07	0.18	1.0
nitrate, as N	0.5	0.3	0.5	2.4	2.4	0.1	10.0
Kjeldhal nitrogen, as N	2,900	380	1,600	7.6	249	560	0.15
ammonia, as N	2,750	340	1,040	4.4	188	424	
phosphorous (total)	19			0.04	2.2	4.2	
phosphorous (soluble)	8.9			0.02	1.3	1.31	
boron		24	120				5.0
aluminum	1,800		3	0.21	5.31	9.2	0.1
arsenic		0.01	0.03				0.05
cadmium		0.01	0.01		0.02	0.01	0.005
chromium	17	0.043	0.82	0.01	0.3	0.26	0.05
copper	54	0.02	0.15	0.03	0.18	0.04	1.0
iron (total)	190	3.2	7.1	0.18	5.2	18.3	0.3
lead	63	0.03	0.1	0.01	0.34	0.19	0.05
manganese		0.2	0.16	0.04	4.2	0.05	0.05
nickel	4.4	0.15	0.4	0.01	0.22	0.34	
selenium		0.01	0.01				0.01
zinc	100	0.03	0.47	0.05	0.55	0.56	5.0

Notes:

Location of sampling sites shown in Figure 6.

[a] Analyzed by the Ontario Ministry of the Environment in 1980.
[b] Analyzed for the Waterloo Research Institute by the Ontario Ministry of the Environment in 1983.
[c] Sampled in July 1980 and analyzed by the Ontario Ministry of the Environment.
[d] Values reported are average of three samples collected in 1979, 1980 and 1981 and analyzed by The Ontario Ministry of the Environment.
[e] Values reported are average of two samples taken in July 1980 and June 1981 and analyzed by the Ontario Ministry of the Environment.
[f] Ontario Ministry of the Environment Drinking Water Objectives (where available).
[g] Measured in pH units 0-14 (7 is neutral; below 7 is acidic; above 7 is alkaline).
[h] Measured in µohms/cm (µs).
[i] Expressed in standard units as $CaCO_3$ equivalents.

Where no data are given in this table, the parameter was not analyzed.

APPENDIX 3 - Table 2: **Monitoring of Surface Waters for Water Quality and Inorganic Parameters**
parts per million (unless otherwise shown)

	Site 19 (Blackhole)			Site 2 (Upstream)			Site 22 (Downstream)			Site 26 (Albion Falls[a])			Drinking Water Criteria[b]
	July '79	July '80	June '81	July '79	April '80	July '81	July '79	July '80	July '81	'79	'80	'81	
pH[c]	8.2	8.4	8.0	8.1	8.0	8.0	8.2	7.8	7.9	8.0	8.0	7.8	6.5 to 8.5
BOD(biological oxygen demand)	110	210	2.2	1.6	1.4	1.0	10	3.5	2.0	3.3	1.5	2.6	
COD(chemical oxygen demand)	2,000	280	48	20	20	30	67	46	38	34	15		
conductivity[d]	17,600	16,900	1,950	1,310	1,330	1,750	1,650	2,050	2,100	1,390	1,193	1,545	
chloride	4,120	3,880	259	97	163	173	206	218	267	163	124	200	250
alkalinity[e]	4,867	2,840	214	166	210	215	180	443	123				30-500
nitrite, as N	0.1	0.1	0.01	0.07	0.08	0.05	1.2	0.76	0.02	0.5	0.08	0.22	1.0
nitrate, as N	0.1	0.2	6.75	1.2	1.7	2.2	2.7	2.9	4.6	1.1	1.9	2.5	10.0
Kjeldahl nitrogen, as N	380	362	4.8	0.8	0.6	0.58	6.8	7.4	3.0	3.58	1.9	1.4	.15
ammonia, as N	300	265	0.05	0.2	0.1	0.01	5.0	6.3	0.01	2.6	1.09	0.63	
phosphorous (total)	3.0	3.3	0.36	0.12	0.1	0.09	0.08	0.02	0.05	0.06	0.06	0.05	
phosphorus (soluble)	2.1	1.8	0.01	0.06	0.02	0.04	0.02	0.02	0.03	0.01	0.02	0.02	
aluminum	9.7	5.9	0.34	0.26	2.0	0.75	0.09	0.18	0.47				0.1
arsenic					0.002			0.001					0.05
cadmium	0.05	0.02	0.001	0.005	0.005	0.001	0.005	0.007	0.001	0.005	0.005		0.005
chromium	0.55	0.34	0.006	0.02	0.02	0.007	0.02	0.003	0.006				0.05
copper	0.40	0.13	0.02	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.01	0.01	1.0
iron (total)	7.0	8.2	0.33	2.9	2.9	0.82	0.22	0.23	0.5	0.76	1.0	0.44	0.3
lead	0.30	0.72	0.01	0.03	0.03	0.01	0.03	0.03	0.03	0.03	0.03	0.02	0.05
manganese	12	0.48	0.09	0.04		0.07	0.05	0.08	0.06				0.05
nickel	0.35	0.30	0.01	0.02	0.02	0.07	0.02	0.01	0.01	0.02	0.02	0.01	
zinc	1.2	0.38	0.08	0.09	0.11	0.15	0.01	0.07	0.07	0.06	0.08	0.09	5.0

Notes: Location of sampling sites shown in Figure 6.

All samples analyzed by the Ontario Ministry of the Environment.

[a] Values reported are average of 12 monthly samples for 1979 through 1981.
[b] Ontario Ministry of the Environment Drinking Water Objectives (where available).
[c] Measured in pH units 0-14 (7 is neutral; below 7 is acidic; above 7 is alkaline).
[d] Measured in μohms/cm (μs).
[e] Expressed in standard units as $CaCO_3$ equivalents.

Where no data are given in this table, the parameter was not analyzed.

APPENDIX 3 Table 3: GC-MS Analyses of Leachate
parts per billion

	Site 3^{a}	Site 9^{a}	Site 11^{b}	Site 12^{a}	Site 15^{c}	Site 18^{a}	Site 32^{d}	RQL^{e}	Drinking Water Criteria^{f-g}
Aromatic Hydrocarbons									
benzene ^{h}	1.9	1.1	ND	2.8	6.9	9.1	3.6	1.0	1.0^{g}
toluene ^{h}	BRQL	BRQL	1.3	BRQL	229	12.1	30.4	1.0	50.0^{g}
xylenes ^{h}	14.7	BRQL	164	63.7	332	30.0	142.0	1.0	50.0^{g}
ethylbenzene ^{h}	1.1	ND	24.1	ND	76.0	14.2	9.2	1.0	50.0^{g}
C$_3$-benzenes ^{h}	3.0	BRQL	1396	BRQL	275	18.2	13.8	1.0	
C$_4$-benzenes ^{h}	2.1	2.6	D	19.3	212	3.0	3.2		
C5-benzenes			D		D				
styrene ^{h}	ND	ND	2.6	BRQL	ND	ND	37.1		50.0^{g}
indane	D	ND	ND	D	ND	D	D		
methylindanes	D	D	ND	D	ND	D	D		
Polycyclic Aromatic Hydrocarbons (PAHs)									
naphthalene ^{h}	BRQL	BRQL	382	BRQL	D	28.5	11.8	0.4	10.0^{g}
methylnaphthalenes	BRQL	BRQL	77.2	BRQL	ND	3.5	BRQL	0.5	
1,2-dimethylnaphthalene ^{h}	BRQL	ND	ND	BRQL	ND	6.2	2.0	2.6	
tetrahydronaphthalene			ND	D	ND				
acenaphthene ^{h}	0.5	ND	8.1	1.9	24	2.5	1.3	0.4	20.0^{g}
anthracene ^{h}	ND	ND	ND	12.8	ND	3.9	19.8	0.3	50.0^{g}
2-methylanthracene ^{h}	BRQL	ND	ND	BRQL	ND	1.4	BRQL	0.8	
phenanthrene ^{h}	0.8	BRQL	ND	5.5	26	2.9	3.8	0.3	50.0^{g}
methylphenanthrene			ND		156				
1H-phenalene			ND		140				
fluoranthene ^{h}	BRQL	BRQL	2.6	1.8	260	BRQL	112.5	0.4	50.0^{g}
pyrene ^{h}	BRQL	BRQL	ND	1.9	19	BRQL	118.0	2.5	50.0^{g}
9H-fluorene ^{h}	1.6	ND	ND	5.3	ND	2.1	ND	2.4	50.0^{g}
4H-cyclopenta-d,e,f-phenanthrene		ND		17					
Halogenated Hydrocarbons									
dichloromethane ^{h}	19.7	BRQL	ND	BRQL	ND	BRQL	21800	5.0	50.0^{g}
chloroform ^{h}	BRQL	BRQL	1.3	BRQL	1.0	BRQL	23.0	1.0	350.0
bromoform ^{h}	ND	ND	0.3	ND	ND	ND		1.0	50.0^{g}
carbon tetrachloride			BRQL		ND		ND	1.0	0.4^{g}
1,2-dichloroethane			ND		ND		ND	1.0	3.8^{g}
1,1,1-trichloroethane ^{h}	ND	ND	BRQL	ND	ND	ND	ND	1.0	50.0^{g}
1,1,2-trichloroethane			BRQL		ND		ND	1.0	0.6^{g}
vinyl chloride			ND		D		ND	3.0	0.3^{g}
1,2-dichloroethene			ND		10.2		ND	1.0	50.0^{g}
trichloroethene ^{h}	ND	ND	ND	ND	ND	1.3	BRQL	1.0	3.0^{g}
tetrachloroethene ^{h}	ND	ND	BRQL	ND	ND	1.0	ND	1.0	0.7^{g}
chlorobenzene ^{h}	BRQL	BRQL	4.0	BRQL	BRQL	BRQL	ND	1.0	20.0^{g}
dichlorobenzenes ^{h}	BRQL	BRQL	4.0	29.4	ND	BRQL	10.7	1.0	20.0^{f}
2-chloronaphthalene ^{h}	ND	ND	ND	ND	ND	BRQL			10.0^{f}
polychlorinated biphenyls (PCBs)	ND	ND	ND	ND	68	ND		40.0	3.0^{i}
Alcohols & Ethers									
t-butanol			ND		29.0				
1,1-dimethylbenzyl alcohol			154		190				
3,3,5-trimethyl-cyclohexanol			ND		202				
α-terpineol			ND		539				
diethyl ether	2.3	BRQL	D	3.8	BRQL	7.9	86.1	2	
diisopropyl ether	ND	ND	D	D	ND	ND			
1,3-dimethoxy-2-propanol			ND		16				

Appendix 3 Table 3

	Site 3[a]	Site 9[a]	Site 11[b]	Site 12[a]	Site 19[c]	Site 18[a]	Site 32[d]	RQL[e]	Drinking Water Criteria[f-g]
Aldehydes & Ketones									
formaldehyde			ND		1.0				
acetaldehyde			ND		1.0				
acetone[h]	13.01	3.1	D	7.1	BRQL	31.9	1002	2	
2-butanone[h]	ND	ND	ND	ND	2.6	ND	525.0	1	
3-pentanone			ND		D				
3-methyl-2-butanone			D		50.3		D		
4-methyl-2-pentanone			ND		10.2				
3-methyl-2-hexanone			D		ND				
3-heptanone			ND		88.8				
2,4-dimethyl-3-pentanone	D	D	D	D	ND	D	D		
3,3,5-trimethyl-cyclohexanone			ND		660		D		
isophorone[h]	BRQL	ND	ND	5.5	ND	ND		0.4	50.0[g]
camphor			D		331				
1-phenylethanone			ND		D				
1-methylphenylethanone			ND		D				
octahydromethylnaphthalenone			200				ND		
Esters									
4,4-dimethyl-2-oxetanone	D		ND		ND				
diethyl phthalate[h]	ND	ND	7.5	ND	ND	ND	ND	5.0	50.0[g]
di-n-butyl phthalate[h]	3.9	5.2	83.6	10.3	73	23.4	BRQL		50.0[g]
bis-(2-ethylhexyl)-phthalate[h]	240	201	ND	167	330	167	360.0	.09	4.0[g]
butyl benzyl phthalate[h]	6.1	6.7	ND	ND	ND	8.1		0.8	50.0[g]
triethyl phosphate			17.4		ND				
Aromatic Acids									
benzoic acid			9.4		D				
methyl benzoic acid			ND		200				
dimethyl benzoic acid			2.4		37		D		
phenylpropanoic acids			ND		1110				
phenylbutanoic acids			ND		348				
ethylbenzenebutanoic acid			ND		880				
butyl benzoic acid			ND		732				
Phenols									
phenol[h]	ND	ND	12.3	ND	92	105	98.1	1.5	2.0[f]
cresols[h]	ND	ND	ND	ND	134	9.1	25.7	3.0	2.0[f]
xylenols[h]	ND	BRQL	40.8	BRQL	376	36.4	10.5	2.0	2.0[f]
C3-phenols			ND		214		D		2.0[f]
butylatedhydroxytoluene			ND		49				
methylene-bis-phenols			ND		840				
methylene-bis-methylphenol			ND		63				
Aromatic Amines									
aniline[h]	ND	ND	72.8	ND	ND	ND	13		1.0[g]
N-methylaniline			117		ND				
N,N-dimethylaniline			109		ND				
Heterocyclic Compounds									
2,3-epoxybutane			ND		D				
1,3-epoxy-4-methylpentane			ND		D				

Appendix 3 Table 3

	Site 3[a]	Site 9[a]	Site 11[b]	Site 12[a]	Site 15[c]	Site 18[a]	Site 32[d]	RQL[e]	Drinking Water Criteria[f,g]
tetrahydrofuran [h]	1043	12.5	D	343	23.9	330	3700	1.0	50.0[g]
methyltetrahydrofuran-methanol			ND		87				
1,3-dioxolane			ND		3.8				
2-et4-methyl-1,3-dioxolane			ND		D				
1,3-dioxane			ND		1.0				
1,4-dioxane [h]	2610	103	D	1951	26.6	4926	18663	80.0	
dimethyl dioxane			ND		15.0				
1,3,5-trioxane			ND		43				
oxathiolane			ND		200		D		
methylpyridine [h]	ND	ND	ND	ND	11	ND			
isoquinoline [h]	ND	ND	3.4	ND	ND	2.3	BRQL	5.5	
tetrahydrofuranylindole			ND		26				
phenyl-o-tolyl-2-pyrazoline			ND		76				
benzothiazole [h]	ND	ND	29.3	BRQL	D	ND	ND		
hydroxybenzothiazole			ND		990				
benzothiazolone			356		ND		D		
Miscellaneous Sulfur & Nitrogen Compounds									
dimethyl sulfide	D	ND	ND	ND	ND	D			
dimethyl disulfide	D	ND	ND	D	ND	D			
3-(1-methylethyl) thio-1-propene			ND		150				
ethyl cyanide			ND		1.1				
trimethylbenzene-sulfonamide			ND		17				

Notes: Location of sampling sites shown in Figure 6.

a Analyzed by Mann Testing Laboratories
b Analyzed by Standard University.
c Analyzed by the Ontario Ministry of the Environment.
d Samples from leachate collection manhole collected in July 1983, March, October and December 1984, and analyzed by Mann Testing Laboratories. Highest values reported here. (Target compound analysis)
e RQL means Reliable Quantification Limit of the analytical method.
f Ontario Ministry of the Environment Drinking Water Objectives (where available).
g New York State Proposed Drinking Water Toxics Standards, January 1985 (where available).
h Means targeted compound in the analyses of Sites 3,9,12,18, and 32 by Mann Testing Laboratories

D means the compound is detected but the amount not determined.
BRQL means detected but Below Reliable Quantification Limit.
ND means the compound was searched for; if present, the amount is below the detection limit.

Where no data are given in this table, the presence or absence of the compound was not reported by the laboratory.

APPENDIX 3 Table 4: Target Compounds Not Detected in GC-MS Analyses of Leachate[a]

Polycyclic Aromatic Hydrocarbons (PAHs)

2,3,5-trimethylnaphthalene
acenaphthylene
coronene
perylene
benzo (a) anthracene
benzo (a) pyrene
benzo (k) fluoranthene
benzo (b) fluoranthene
chrysene
dibenzo (a,h) anthracene
benzo (g,h,i) perylene
indeno (1,2,3-CD) pyrene

Halogenated Hydrocarbons

1,1-dichlorethane
hexachloroethane
1,1-dichloroethene
hexachlorobutadiene
hexachlorocyclopentadiene
1,2,4-trichlorobenzene
hexachlorobenzene

Halogenated Ethers

bis(2-chloro ethyl) ether
bis(2-chloroisopropyl) ether
bis(2-cloroethoxy) methane
4-chlorophenyl phenyl ether
4-bromophenyl phenyl ether

Halogenated Acids

2,4-dichlorophenoxyacetic acid
2,4,5-trichlorophenoxyacetic acid
2-(2,4,5-trichlorophenoxy)
propionic acid (silvex)

Halogenated Phenols

2-chlorophenol
2,4-dichlorophenol
2,4,5-trichlorophenol
2,4,6-trichlorophenol
pentachlorophenol

Esters

dimethyl phthalate

Amines

benzidene
3,3-dichlorobenzidene

Nitro Compounds

nitrobenzene
2,4-dinitrotoluene
2,6-dinitrotoluene
2-nitrophenol
4-nitrophenol
2,4-dinitrophenol
4,6-dinitro-o-cresol

Heterocyclic Compounds

dibenzofuran
benzothiophene
4-methyl pyridine

Miscellaneous Nitrogen & Sulfur Compounds

carbon disulfide
1,2-diphenyl hydrazine
N-methyl-N-nitroso-methanamine
N-nitrosodi-n-propylamine
N-nitroso-diphenylamine

Notes:

[a] These targeted compounds were not detected by Mann Testing Laboratories in analysis of leachate sites 3, 9, 12, and 18 as shown in Figure 6 and Table 3 of Appendix 3. The absence of these compounds within the detection limit of the instrument is definitely confirmed.

APPENDIX 3 Table 5: Non-Targeted Compounds Detected in GC-MS Monitoring of Leachate Collection Manhole[a]

Alcohols & Ethers

5-hexen-2-ol
dimethoxymethane
1,1'[methylenebis(oxy)] bis-ethane

Aldehydes & Ketones

isobutylaldehyde
2-pentanone
4-penten-2-one
dimethylbutanone
2-heptanone
3-methyl-2-heptanone
2-methyl-4-octanone
5-methyl-2-(1-methylethyl)-cyclohexanone
2,2,5-trimethyl-3,4-hexanedione

Aromatic Acids

chlorobenzoic acid
dichlorobenzoic acid

Phenols

tetramethyl phenol

Heterocyclic Compounds

2,7,7-trimethyl-3-oxatricyclo[4.1.1.02.4]octane
isoquinalone
methoxy-1,2-benzothiazole
methyl thiethane
tetrahydrothiophene

Other

ethyl mercaptan
0-(2-methylpropyl)-hydroxylamine

Notes:

[a] Mann Testing Laboratories detected these compounds by routine GC-MS scanning. Compounds were not targeted; therefore, identification is tentative and amounts not determined.

APPENDIX 3 Table 6: **GS-MS Monitoring of Surface Water**[a]
(Detected Target Compounds)
parts per billion

	Site 32 (Leachate Collection Manhole)				Site 2 (Upstream)				Site 22 (Downstream)				RQL[f]	Drinking Water Criteria g,h
	1[b]	2[c]	3[d]	4[e]	1[b]	2[c]	3[d]	4[e]	1[b]	2[c]	3[d]	4[e]		
Aromatic Hydrocarbons														
benzene	3.6	ND	BRQL	BRQL	BRQL	ND	ND	ND	BRQL	ND	ND	ND	1.0	10.0[h]
toluene	30.4	BRQL	2.6	3.5	BRQL	ND	ND	ND	BRQL	ND	ND	ND	1.0	50.0[h]
xylenes	142	ND	13.5	49.3	ND	ND	BRQL	ND	BRQL	ND	BRQL	ND	1.0	50.0[h]
ethylbenzene	9.2	ND	ND	ND	ND	ND	ND	ND	BRQL	ND	ND	ND	1.0	50.0[h]
trimethylbenzenes	15.8	ND	3.0	5.4	ND	ND	ND	ND	ND	ND	ND	ND	1.0	50.0[h]
tetramethylbenzenes	5.2	ND	1.3	1.1	ND	ND	ND	ND	ND	ND	ND	ND	1.0	
styrene	37.1	ND	ND	ND	BRQL	ND	ND	ND	1.0	ND	ND	ND	1.0	50.0[h]
Polycyclic Aromatic Hyrdocarbons (PAHs)														
naphthalene	11.8	BRQL	BRQL	BRQL	ND	BRQL	2.9	ND	ND	3.2	BRQL	ND	0.4	10.0[h]
methylnaphthalenes	BRQL	ND	BRQL	BRQL	ND	2.2	BRQL	ND	ND	5.5	ND	ND	0.5	
1,2-dimethylnaphthalene	BRQL	ND	BRQL	ND	ND	13.6	ND	ND	ND	10.0	ND	ND	0.6	
acenaphthylene	ND	BRQL	BRQL	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.5	
acenaphthene	NR	1.1	1.3	ND	NR	ND	1.7	ND	NR	ND	0.7	ND	0.4	20.0[h]
anthracene	19.8	ND	BRQL	ND	ND	ND	ND	ND	ND	BRQL	ND	ND	0.3	50.0[h]
2-methylanthracene	ND	ND	BRQL	ND	ND	BRQL	ND	ND	ND	BRQL	ND	ND	0.8	
phenanthrene	NR	ND	2.5	3.8	NR	0.6	1.2	BRQL	NR	0.8	ND	BRQL	0.3	50.0[h]
fluoranthrene	10.6	0.5	BRQL	112.5	ND	BRQL	BRQL	BRQL	ND	BRQL	BRQL	ND	0.4	50.0[h]
pyrene	10.5	BRQL	BRQL	118.0	ND	BRQL	BRQL	BRQL	ND	BRQL	BRQL	BRQL	0.5	50.0[h]
benzo(a)anthracene	3.1	BRQL	BRQL	24.0	ND	ND	BRQL	BRQL	ND	ND	ND	BRQL	0.5	0.002[h]
benzo(k)fluoranthene	NR	BRQL	ND	BRQL	NR	ND	ND	BRQL	NR	ND	ND	BRQL	0.4	0.002[h]
benzo(b)fluoranthene	ND	ND	ND	BRQL	ND	ND	ND	BRQL	ND	ND	ND	BRQL	0.6	0.002[h]
benzo(a)pyrene	NR	BRQL	ND	BRQL	NR	ND	BRQL	BRQL	NR	ND	ND	BRQL	0.3	0.002[h]
9H-fluorene	NR	ND	ND	ND	NR	2.0	1.4	ND	NR	BRQL	1.8	ND	0.4	50.0[h]
chrysene	NR	BRQL	BRQL	24.0	NR	ND	BRQL	BRQL	NR	ND	ND	BRQL	0.4	0.002[h]
dibenzo(a,h)anthracene	NR	BRQL	ND	BRQL	NR	ND	ND	BRQL	NR	ND	ND	BRQL	4.0	
benzo(g,h,i)perylene	NR	BRQL	ND	BRQL	NR	ND	ND	BRQL	NR	ND	ND	BRQL	2.0	
indeno(1,2,3-cd)pyrene	NR	ND	ND	BRQL	NR	ND	ND	BRQL	NR	ND	ND	BRQL	1.3	0.002[h]
Halogenated Hydrocarbons														
dichloromethane	222	18.8	21,800	11,700	BRQL	31.5	BRQL	ND	15.2	31.8	ND	BRQL	5.0	50.0[h]
chloroform	23	2.2	ND	ND	BRQL	1.4	ND	BRQL	1.7	1.0	ND	BRQL	1.0	350.0[g]
1,1-dichloroethane	3.7	12.6	ND	2.4	ND	ND	ND	ND	BRQL	ND	ND	ND	1.0	50.0[h]
1,1,1-trichloroethane	ND	ND	ND	ND	ND	ND	ND	ND	BRQL	ND	ND	ND	1.0	50.0[h]
trichloroethene	BRQL	ND	ND	ND	BRQL	ND	ND	BRQL	BRQL	ND	BRQL	BRQL	1.0	5.0[h]
tetrachloroethene	ND	ND	ND	ND	1.3	ND	ND	ND	BRQL	ND	ND	ND	1.0	0.7[h]
dichlorobenzenes	11.8	7.7	3.9	3.3	BRQL	BRQL	BRQL	ND	BRQL	BRQL	BRQL	ND	1.0	20.0[h]
Ethers														
diethyl ether	86.1	7.3	ND	ND	ND	ND	ND	ND	14.7	ND	ND	ND	2.0	
bis-(2-chloroethyl)ether	NR	ND	ND	ND	NR	BRQL	ND	ND	NR	BRQL	ND	ND	1.0	0.03[h]
Ketones														
acetone	1,002	ND	ND	ND	BRQL	ND	4.8	ND	BRQL	ND	ND	ND	2.0	
2-butanone	323	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.0	

Appendix 3 Table 6

	Site 32 (Leachate Collection Manhole)				Site 2 (Upstream)				Site 22 (Downstream)				RQL[f]	Drinking Water Criteria [g,h]
	1[b]	2[c]	3[d]	4[e]	1[b]	2[c]	3[d]	4[e]	1[b]	2[c]	3[d]	4[e]		
Esters														
diethyl phthalate	ND	ND	ND	ND	ND	ND	ND	BRQL	ND	ND	ND	ND	3.0	50.0[h]
di-n-butyl phthalate	NR	BRQL	ND	2.3	NR	ND	BRQL	1.2	NR	ND	ND	1.2	0.4	50.0[h]
di-n-octyl phthalate	NR	ND	ND	BRQL	NR	ND	ND	ND	NR	ND	ND	ND	1.3	50.0[h]
bis(2-ethylhexyl) phthalate	13.1	360	17.6	31.6	24.3	24.8	6.0	13.2	21.2	92.0	7.2	7.1	0.9	4.0[h]
Phenols														
phenol	98.1	BRQL	BRQL	BRQL	BRQL	ND	ND	ND	70.2	ND	ND	1.5	1.3	2.0[g]
cresols	25.7	ND	ND	ND	ND	ND	ND	ND	11.1	ND	ND	ND	3.0	2.0[g]
xylenols	10.5	7.4	BRQL	BRQL	ND	BRQL	ND	ND	3.6	BRQL	BRQL	ND	2.0	2.0[g]
pentachlorophenol	NR	BRQL	ND	ND	NR	BRQL	ND	ND	NR	BRQL	ND	ND	3.0	2.0[g]
Aromatic Amines														
aniline	13	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND		1.0[h]
Heterocyclic Compounds														
tetrahydrofuran	1,213	1,349	2,437	3,700	BRQL	ND	ND	ND	1.4	ND	4.5	2.7	2.0	50.0[h]
1,4-dioxane	18,663	949	6,743	16,700	ND	ND	ND	ND	ND	ND	68.4	ND	1.0	
dibenzofuran	ND	ND	ND	6.3	ND	ND	BRQL	ND	ND	ND	ND	ND	0.3	
benzothiophene	ND	ND	BRQL	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.4	
isoquinoline	ND	BRQL	ND	ND	ND	ND	BRQL	ND	ND	1.4	ND	ND	0.3	
Other														
carbon disulfide	BRQL	ND	ND	ND	BRQL	ND	ND	ND	BRQL	ND	ND	ND	1.0	
N-nitrosodiphenylamine	NR	BRQL	ND	ND	NR	ND	ND	ND	NR	ND	ND	ND	0.4	

Notes: Location of sampling sites shown in Figure 6.

[a] All analyses by Mann Testing Laboratories. (Target compound analysis)
[b] Sampled in July 1983.
[c] Sampled in March, 1984.
[d] Sampled in October, 1984.
[e] Sampled in December, 1984.
[f] RQL means Reliable Quantification Limit of the analytical method.
[g] Ontario Ministry of the Environment Drinking Water Objectives (where available).
[h] New York State proposed Drinking Water Toxics Standards, January 1983 (where available).

BRQL means Detected but amount is Below Reliable Quantification Limit.
ND means the compound was searched for; if present, the amount is below the detection limit.
NR means the presence or absence of the compound was not reported by the laboratory.

APPENDIX 3 Table 7: Target Compounds Not Detected in GC-MS Monitoring of Surface Waters[a]

Polycyclic Aromatic Hydrocarbons (PAHs)

trimethyl naphthalenes
coronene
perylene
benzo(C) pyrene

Halogenated Hydrocarbons

chloromethane
bromomethane
dichlorodifluoromethane
trichlorofluoromethane
bromodichloromethane
dibromochloromethane
carbon tetrachloride
chloroethane
1,2-dichloroethane
1,1,2-trichloroethane
1,1,2,2-tetrachloroethane
hexachloroethane
vinyl chloride
1,1-dichloroethene
1,2-dichloroethene
1,2-dichloropropane
1,3-dichloropropene
hexachlorobutadiene
hexachlorocyclopentadiene
benzyl chloride
chlorobenzenes
1,2,4-trichlorobenzene
hexachlorobenzene

Halogenated Ethers

bis-(chloromethyl)ether
2-chloroethyl vinyl ether
bis(2-chloroethoxy) methane
4-chlorophenyl phenyl ether
4-bromophenyl phenyl ether

Halogenated Acids

2,4-dichloro phenoxyacetic acid
2,4,5-trichloro phenoxyacetic acid
2-(2,4,5-trichlorophenoxy) propionic acid (silvex)

Halogenated Phenols

2-chlorophenol
2,4-dichlorophenol
2,4,5-trichlorophenol
2,4,6-trichlorophenol
pentachlorophenol

Aldehydes

acrolein

Esters

dimethyl phthalate
butyl benzyl phthalate

Amines

benzidene
3,3-dichlorobenzidene

Nitro Compounds

nitrobenzene
2,6-dinitrotoluene
2,4-dinitrotoluene
2-nitrophenol
4-nitrophenol
2,4-dinitrophenol
4,6-dinitro-o-cresols

Heterocyclic Compounds

1-methyl-2-pyrrolidine
4-methyl pyridine
benzothiazole

Miscellaneous Nitrogen & Sulfur Compounds

carbon disulfide
acrylonitrile
1,2-diphenyl hydrazine
N-nitroso-di-N-propylamine
N-methyl-N-nitrosomethanamine

Notes:

[a] These targeted compounds were not detected by Mann Testing Laboratories in the monitoring of the leachate collection manhole, upstream or downstream sites (see Table 6 of Appendix 3). The absence of these compounds within the detection limit of the instrument is definitely confirmed.

APPENDIX 4 Table 1: **Water Quality and Inorganic Analysis of Groundwaters Near to the Landfill[a]**
parts per million (unless otherwise shown)

Sampling Depth	Site 15 (Leachate)	Site 7 25.9m	Site 10[a] 6.4m	Site 13 48.5m	Site 20[a] 27.9m	Site 21[a] 12.2m	Site 30[a] 21m	Site 33 15.6m	Site 37[a] 4.6m	Drinking Water Criteria[b]
pH[c]	7.86	5.9	6.9	6.2	6.0	5.9	6.9	6.8	7.1	6.5 to 8.5
conductivity[d]	25,900	72,000	11,220	122,000	142,000	97,000	72,500	122,000	3,050	
TOC (total organic carbon)	NR	NR	311	NR	155	39	567	876	52	5
DOC (dissolved organic carbon)	4,600	240	180	NR	80	NR	675	1,420	145	
hardness[e]	401.5	26,005	1,977	40,789	60,100	31,169	23,376	48,139	664	80-100
calcium	19	7,200	459	10,400	17,000	8,650	6,550	12,700	121	
magnesium	86	1,950	203	3,600	4,300	2,325	1,710	4,000	88	
sodium	4,700	9,600	1,333	19,800	25,000	15,350	10,950	19,900	465	below 20
potassium	135	187	248	370	390	333	203	310	39	
chloride	4,362	30,900	1,901	58,220	82,240	45,820	32,150	62,120	482	250
alkalinity[e]	9,130	340	1,328	184	157	32	209	115	646	30-500
sulphate	130	1,140	1,690	1,200	675	932	1,218	1,080	265	500
fluoride, as N	6.6	1.5	.705	1.0	NR	NR	NR	NR	1.2	1.2 (natural 2.4)
nitrite, as N	0.41	0.05	0.02	0.03	0.03	0.03	0.4	0.02	0.02	1
nitrate, as N	0.5	0.3	0.2	2.0	0.1	0.1	0.6	1.8	0.1	10
Kjeldhal nitrogen, as N	1,600	NR	143	75.0	60	50.0	25	55	23	0.15
ammonia, as N	1,040	50	135	61.0	45	35.0	25	43	19	
boron	120	6.8	7.3	7.0	6.2	2.8	3.3	3.8	3.6	5
arsenic	0.03	0.001	0.001	0.001	0.001	0.001	0.063	0.001	0.001	0.05
cadmium	0.01	0.01	0.016	0.005	0.010	0.005	0.004	0.005	0.004	0.005
chromium	0.82	0.2	0.04	0.03	0.120	0.4	0.239	0.13	0.02	0.05
copper	0.15	0.4	0.07	0.38	0.720	0.41	0.36	.4	0.02	1
iron (total)	7.1	0.5	0.098	0.64	34.0	7.3	0.5	0.14	12	0.3
lead	0.1	0.06	0.06	0.05	0.150	0.08	0.04	0.06	0.04	0.05
manganese	0.16	1.1	0.03	0.33	3.9	1.7	1.0	0.75	1.37	0.05
nickel	0.4	0.02	0.072	0.006	0.014	0.01	0.009	0.006	0.037	
selenium	0.01	0.001	0.003	0.001	0.004	0.001	0.001	0.001	0.001	0.01
zinc	0.47	0.034	0.022	0.009	0.073	0.41	0.6	0.05	0.062	5

Notes: Location of sampling sites shown in Figure 6.

All Samples collected between May and November, 1983 and analyzed for the Waterloo Research Institute by the Ontario Ministry of the Environment.

[a] Values reported are average of two samples.
[b] Ontario Ministry of the Environment Drinking Water Objectives (where available).
[c] Measured in pH units 0-14 (7 is neutral; below 7 is acidic; above 7 is alkaline).
[d] Measured in μohms/cm (μs)
[e] Expressed in standard unit as $CaCO_3$ equivalents.

NR means the presence or absence of the compound was not reported by the laboratory.

APPENDIX 4 Table 2: **Water Quality and Inorganic Analyses of Groundwaters Distant from the Landfill**
parts per million (unless otherwise shown)

Sampling Depth	Site 15 (leachate)	Site 1 40m	Site 4[a] 10m	Site 14[a] 31.7m	Site 23[a] 12.6m	Site 25[a] 7.2m	Site 27[a] 23.5m	Site 28 5.9m	Site 38 10.5m	Drinking Water Criteria[b]
pH[c]	7.86	6.22	7.24	6.43	6.68	7.08	7.03	6.94	7.37	6.5 to 8.5
conductivity[d]	25,900	105,000	2,924	149,000	61,000	3,886	79,500	10,000	1,970	
TOC (total organic carbon)	NR	NR	20.5	9.6	64.3	NR	2,960	8.3	NR	5
DOC (dissolved organic carbon)	4,600	3,300	2.3	NR	NR	44	3,550	NR	10.6	
hardness[e]	401.5	36,730	1,462	59,244	20,027	1,286	26,700	3,117	1,007	80-100
calcium	19	10,600	493	16,450	5,525	334	7,100	813	260	
magnesium	86	2,500	57	4,425	1,518	110	2185	265	87	
sodium	4,700	16,700	134	43,825	8,425	356	11,800	1,180	58	below 20
potassium	135	317	14	468	161	18.7	207	25.0	5.4	
chloride	4,362	52,560	190	91,281	24,700	758	37,270	2,906	145	250
alkalinity[e]	9,130	118	190	45	293	406	114	277	362	500
sulphate	130	840	1,318	1,053	2,050	623	1,040	1,110	600	500
fluoride	6.6	1.0	0.75	NR	0.60	0.36	NR	0.70	0.77	1.2 (natural 2.4)
nitrite, as N	0.41	0.02	0.15	0.03	0.02	0.01	0.25	0.01	0.01	1
nitrate, as N	0.5	6.2	0.2	0.1	0.2	0.15	0.4	0.01	0.2	10
Kjeldhal nitrogen, as N	1,600	70.0	2.6	65.0	NR	2.0	55.0	12.5	0.6	0.15
ammonia, as N	1,040	39.5	0.2	52.3	31	1.4	26.9	2.6	0.1	
boron	120	3.60	0.62	4.4	9.8	0.50	4.45	1.80	0.31	5
arsenic	0.03	0.003	0.001	0.001	0.001	0.001	0.002	0.02	0.009	0.05
cadmium	0.01	0.005	0.01	0.03	0.009	0.009	0.004	0.005	0.001	0.005
chromium	0.82	0.240	0.04	0.11	0.03	0.04	0.52	0.03	0.012	0.05
copper	0.15	0.52	0.05	0.88	0.37	0.03	0.34	0.06	0.015	1
iron (total)	7.1	13.0	0.33	0.89	0.35	2.37	0.33	0.05	0.05	0.3
lead	0.1	0.05	0.05	0.60	0.05	0.04	0.04	0.03	0.02	0.05
manganese	0.16	2.60	0.05	1.35	0.51	0.52	1.40	0.08	0.02	0.05
nickel	0.4	0.01	0.02	0.08	0.02	0.02	0.02	0.02	0.01	
selenium	0.01	0.001	0.004	0.002	0.001	0.001	0.002	0.001	0.001	0.01
zinc	0.47	0.08	0.01	0.09	0.04	0.13	0.065	0.03	0.009	5

Notes: Location of sampling sites shown in Figure 6.

All samples collected between May and December 1983 and analyzed for the Waterloo Research Institute by the Ontario Ministry of the Environment.

[a] Values reported are average of two samples.
[b] Ontario Ministry of the Enviroment Drinking Water Objectives (where available).
[c] Measured in pH units 0-14 (7 is neutral; below 7 is acidic; above 7 is alkaline).
[d] Measured in μohmn/cm (μs).
[e] Expressed in standard units as $CaCo_3$ equivalents.

NR means the presence or absence of the compound was not reported by the laboratory.

APPENDIX 4 Table 3: GC-MS Analyses Of Groundwaters Near To The Landfill
parts per billion

Sampling Depth	Site 13 (Leachate)	Site 7^a 25.9m	Site 10^b 6.1m	Site 13^c 48.3m	Site 20^a 3.7m	Site 21^c 12.2m	Site 30^a 21m	Site 33^c 13.6m	Site 37^a 9.6m	Site 37^a 26.8m	RQL^d	Drinking Water Criteria^e,f
Aromatic Hydrocarbons												
benzene	6.9	0.9	3.3	4.9	0.9	9.0	1.3	ND	2.6		1.0	1.0^f
toluene	229	3.8	2.0	43.6	0.5	8.2	2.2	83.0	BRQL		1.0	90.0^f
xylenes	332	6.7	9.8	3.6	BRQL	2.0	4.1	2.8	1.1		1.0	50.0^f
ethylbenzene	69.6	2.1	3.1	BRQL	BRQL	BRQL	BRQL	BRQL	BRQL		1.0	50.0^f
C_3-benzenes	375	D	3.8	ND	BRQL	ND	ND	ND	ND		1.0	50.0^f
C_4-benzenes	312	ND	ND	ND	ND	ND	ND	ND	ND		1.0	
C_5-benzenes	D	ND	ND	ND	ND	ND	ND	ND	ND		1.0	
styrene	2.6	ND	BRQL	ND	BRQL	ND	ND	ND	ND		1.0	30.0^f
indane	ND	ND	ND	ND	ND	ND	ND	ND	ND			
Polycyclic Aromatic Hydrocarbons (PAHs)												
naphthalene	D		0.3	D	0.8	D	D	ND		D	0.4	10.0^f
methylnaphthalenes	ND		0.3	ND	0.3	ND	ND	ND		ND	0.3	
acenaphthene	29		ND	ND	ND	ND	ND	ND		ND	0.4	20.0^f
phenanthrene	26		[illegible]	ND	ND	ND	ND	ND		ND	0.3	50.0^f
9H-fluorene	ND		ND	ND	ND	ND	ND	ND		ND	0.4	50.0^f
Halogenated Hydrocarbons												
dichloromethane	ND	BRQL	6.1	BRQL	ND	ND	3.6	39.6	0.9		1.0	50.0^f
chloroform	1.8	ND	2.8	1.2	BRQL	2.8	ND	1.6	ND		1.0	350.0^g
bromoform	ND	ND	ND	ND	BRQL	ND	ND	ND	ND		1.0	50.0^f
carbon tetrachloride	ND	ND	BRQL	ND	ND	ND	ND	ND	ND		1.0	0.4^f
1,1-dichloroethane	ND	ND	9.6	ND	ND	ND	ND	5.8	ND		1.0	50.0^f
1,2-dichloroethane	ND	ND	ND	3.3	ND	ND	ND	ND	ND		1.0	0.8^f
1,1,1-trichloroethane	ND	ND	BRQL	3.6	BRQL	9.2	ND	19.1	ND		1.0	50.0^f
1,1,2-trichloroethane	ND	ND	BRQL	ND	ND	ND	ND	ND	ND		1.0	0.6^f
trichloroethene	ND	ND	BRQL	ND	BRQL	ND	ND	ND	ND		1.0	3.0^i
tetrachloroethene	ND	ND	BRQL	ND	BRQL	ND	ND	ND	ND		1.0	0.7^i
chlorobenzene	BRQL	ND	BRQL	(BRQL)^h	BRQL	ND	ND	ND	1.6		1.0	20.0^f
dichlorobenzenes	ND	ND	BRQL	ND	BRQL	ND	ND	ND	ND		1.0	20.0^f
polychlorinated biphenyls(PCBs)	64		ND	ND	ND	ND	ND	ND		ND	3.0	3.0^e
Alcohols & Ethers												
1-butanol	29.0	ND	ND	[illegible]	ND	ND	ND	ND	ND			
2-butanol		ND	ND	ND	ND	ND	D	ND	ND			
pentanols		ND	ND	ND	ND	ND	ND	0.8	ND			
4-penten-2-ol		ND	ND	ND	ND	ND	ND	ND	ND			
4-ethyl-1-octyn-3-ol		ND	ND	ND	ND	D	ND	ND	ND			
3,3,5-trimethylcyclohexanol	202			ND	ND	ND	ND	ND	ND		ND	
α-terpineol	839		ND	ND	ND	ND	ND	ND		ND		
1,1-dimethylbenzyl alcohol	890		22.6	ND	ND	ND	ND	ND		ND		
diethylene glycol			ND	ND	ND	3079	ND	118		ND		
2-butoxyethanol			ND	ND	ND	[illegible]	ND	D		ND		
butyl carbitol			ND	ND	ND	678	ND	19.0		ND		
1,2-diethoxyethane		ND	ND	ND	ND	ND	ND	ND	ND			
Ketones												
acetone	1.6	D	ND	BRQL	ND	3.6	D	BRQL	ND		2.0	
2-butanone	2.6	ND	ND	D	ND	6.3	D	121	ND		1.0	
4-methyl-2-pentanone	10.2	ND	ND	ND	ND	D	ND	ND	ND			
3-methyl-4-heptanone		ND	ND	ND	ND	ND	ND	ND	ND			
3,3,5-trimethylcyclohexanone	202		ND	D	ND	ND	ND	ND		ND	0.4	
camphor	331		ND	D	ND	ND	ND	ND		ND		
fenchone		ND	ND	[illegible]	ND	ND	ND	ND	ND			

Appendix 4 Table 3

Sampling Depth	Site 15 (Leachate)	Site 7^{a} 23.9m	Site 10^{b} 6.4m	Site 19^{c} 48.5m	Site 20^{a} 3.7m	Site 21^{c} 12.2m	Site 30^{a} 21m	Site 33^{c} 13.6m	Site 37^{a} 9.6m	Site 37^{a} 26.8m	RQL^{d}	Drinking Water Criteria^{e,f}
Esters												
propyl propionate			ND	ND	ND	ND	ND	ND		ND		
butyl propionate			ND	ND	ND	ND	ND	D		ND		
diethyl phthalate			2.0	ND	3.3	ND	ND	2.0		D	5.0	30.0^{f}
butyl methyl phthalate			ND	ND	ND	IDM	ND	ND		D		
di-n or di-isobutyl phthalate	73		2.9	40.0	17.3	6.0	D	D		ND	0.6	
di-n or di-isooctyl phthalate			D	5.0	ND	10.0	ND	8.0		ND	1.3	
bis-(2-ethylhexyl) phthalate	150		ND	100	ND	ND	ND	ND		ND	0.9	4.0^{f}
triethyl phosphate	ND		13.8	ND	ND	ND	ND	ND		ND		
tributyl phosphate			ND	ND	ND	ND	ND	ND		ND		
Aromatic Acids												
benzoic acid	D		4.9	ND	0.8	IDM	ND	ND		ND		
dimethyl benzoic acid	37		6.3	ND	ND	ND	ND	ND		ND		
phenylacetic acid			ND	ND	ND	IDM	ND	ND		ND		
butylbenzoic acids	732		ND	8.0	ND	ND	ND	D		ND		
salicylic acid			D	ND	D	IDM	ND	D		ND		
Phenols												
phenols	92		10.5	ND	1.5	ND	ND	ND		ND	1.3	2.0^{e}
cresols	136		ND	ND	ND	ND	ND	ND		ND		2.0^{e}
xylenols	376		16.2	ND	ND	ND	ND	ND		ND	2.0	2.0^{e}
C$_3$-phenols	210		ND	ND	ND	ND	ND	ND		ND	2.0	2.0^{e}
hydroxybiphenol			ND	ND	ND	ND	ND	ND		ND		
methylene-bis-phenols	840		ND	ND	ND	ND	ND	ND		ND		
4-4'-(1-methylethylidene) -bis-phenol			ND	ND	ND	ND	ND	ND		ND		
Aromatic Amines												
aniline	ND		ND	ND	BRQL	ND	ND	ND		ND		1.0^{f}
N-methylaniline	ND		0.7	ND	IDM	ND	ND	ND		ND		
Heterocyclic Compounds												
2-or 4-methyl-1,3 -dioxolane	D	ND	ND	IDM	ND	ND	ND	ND	ND			
tetrahydrofuran	25.9	ND	D	166	ND	2.1	D	271	ND		1.8	30.0^{f}
1,4-dioxane	26.6	ND	ND	BRQL	ND	ND	ND	ND	ND		80.0	
dimethyldioxane	15.6	ND	ND	ND	ND	ND	ND	ND	ND			
2-methylthiophene		ND	ND	ND	ND	ND	D	ND	ND			
1,2,4-trithiolane			ND	ND	ND	ND	ND	ND		ND		
1,3,5-trithiane			ND	ND	ND	ND	ND	ND		ND		
hexathiepane			ND	7.8	ND	ND	D	ND		ND		
oxathiolane	300		ND	ND	ND	ND	ND	ND		ND		
pyrrolidinone, substituted			ND	ND	ND	ND	ND	D		ND		
pyridine		ND	ND	ND	ND	ND	ND	D	ND			
methylpyridine	11		ND	ND	ND	ND	ND	ND		ND		
isoquinoline	ND		1.6	ND	ND	ND	ND	ND		ND	0.3	
oxathiazolone, substituted			ND	ND	ND	ND	ND			D		
benzothiazole	D		4.9	10.0	96.3	238	D	11.0		D		
hydroxybenzothiazole	990		ND	ND	ND	ND	ND	ND		ND		
mercaptobenzothiazole			ND	31.0	ND	8.0	ND	61.0		ND		
benzothiazolone	ND		11.1	ND	67.1	ND	ND	ND		ND		
vitavax^{h}			ND	ND	ND	ND	ND	ND		ND		
octamethylcyclo- tetrasiloxane			ND	ND	ND	ND	ND	ND		D		
Miscellaneous Sulfur & Nitrogen Compounds												
carbon disulfide		ND	D	BRQL	ND	ND	ND	2.2	ND		1.0	
dimethyl disulfide	ND	ND	ND	3.9	ND	ND	ND	0.6	ND			
diethyl disulfide		D	ND	ND	ND	ND	ND	ND	ND			
acrylonitrile		ND	ND	ND	ND	1.9	ND	ND	ND		1.0	0.07^{f}
nonamide			ND	ND	ND	ND	ND	ND		ND		

Appendix 4 Table 3

Notes: Location of sampling sites is shown in Figure 6.

[a] Analyzed by Mann Testing Laboratories.
[b] Analyzed by Stanford University.
[c] Analyzed by the Ontario Ministry of the Environment.
[d] RQL Mean Reliable Quantification Limit of the analytical method.
[e] Ontario Ministry of the Environment Drinking Water Objectives (where available).
[f] New York State Proposed Drinking Water Toxics Standards, January 1985 (where available).
[g] Found at another depth in the same borehole.
[h] Vitavax is 5,6-dihydro-2-methyl-N-phenyl-1,4-oxathiin-3-carboxamide.

BRQL means Detected but Below the Reliable Quantification Limited.
D means the compound was detected but the amount not determined.
ND means the compound was searched for; if present, the amount is below the detection limit.

Where no data are given in this table, the presence or absence of the compound was not reported by the laboratory.

APPENDIX 4 Table 9: GC-MS Analyses Of Components In Groundwaters Distant From The Landfill
parts per billion

Sampling Depth	Site 13 (Leachate)	Site 1b 48.1m	Site 9a 10m	Site 27a 8.4m	Site 27a 12.6m	Site 22 7.3mc	Site 22 16.2mb	Site 27b 23.3m	Site 28b 3.9m	Site 28b 39.1m	BQLd	Drinking Water Criteriae,f
Aromatic Hydrocarbons												
benzene	7.3		BRQL	BRQL		ND	ND	5.3		BRQL	1.0	1.0f
toluene	229		BRQL	BRQL		1.4	4.8			BRQL	1.0	50.0f
xylenes	332		BRQL	BRQL		1.4	0.7			1.3	1.0	50.0f
ethylbenzene	74.0		BRQL	BRQL		ND	0.2			BRQL	1.0	50.0f
C3-benzenes	273		BRQL	BRQL		30	ND			1.2	1.0	50.0f
C4-benzenes	212		ND	ND		16	ND			ND	1.0	
C5-benzenes	D		ND	ND		23	ND			ND	1.0	
styrene	3.6		BRQL	BRQL		ND				BRQL	1.0	50.0f
indane	ND		ND	ND		D				ND		
Polycyclic Aromatic Hydrocarbons (PAHs)												
naphthalene	D	D	BRQL	BRQL	ND	ND		D	D	0.3	0.5	10.0f
methylnaphthalenes	ND	ND	BRQL	BRQL		ND		ND		0.6	0.3	
acenaphthene	29	ND	ND		ND	2.0		ND	ND		0.4	20.0f
phenanthrene	26	ND	ND		ND	ND		ND	ND		0.3	50.0f
9H-fluorene	ND	ND	ND		ND	17.0		ND	ND		0.5	50.0f
Halogenated Hydrocarbons												
dichloromethane	ND		ND	ND		ND	ND			D	3.0	50.0f
chloroform	1.8		BRQL	BRQL		BRQL	ND			BRQL	1.0	190e
bromoform	ND		BRQL	BRQL		ND	ND			BRQL	1.0	90.0f
carbon tetrachloride	ND		ND	ND		ND				BRQL	1.0	0.4f
1,1,-dichloroethane	ND		ND	ND		ND	ND			ND	1.0	
1,2-dichloroethane	ND		ND	ND		ND	ND			ND	1.0	0.8f
1,1,1-trichloroethane	ND		BRQL	BRQL		ND	ND			BRQL	1.0	50.0f
1,1,2-trichloroethane	ND		ND	BRQL		ND				BRQL	1.0	0.6f
trichloroethene	ND		ND	ND		ND				ND	1.0	3.0f
tetrachloroethene	ND		BRQL	BRQL		ND	ND			BRQL	1.0	0.7f
chlorobenzene	BRQL		BRQL	BRQL		ND	ND			BRQL	1.0	20.0f
dichlorobenzenes	ND		BRQL	BRQL		9	ND			BRQL	1.0	20.0f
polychlorinated biphenyls (PCBs)	68	ND	ND		ND	2.0		ND	ND		60	3.0e
Alcohols & Ethers												
1-butanol	2.9		ND	ND		ND	ND			ND		
2-butanol			ND	ND		ND	ND			ND		
pentanols			ND	ND		ND				ND		
4-penten-2-ol			ND	ND		ND	ND			D		
4-ethyl-1-octyn-3-ol			ND	ND		ND	ND			ND		
3,3,5-trimethylcyclohexanol	202	ND	ND		ND	27		ND	ND			
α-terpineol	839	ND	ND		ND	97		ND	ND			
1,1-dimethylbenzyl alcohol	890	ND	ND		7.1	ND		ND	ND			
diethylene glycol		ND	ND		ND	ND	[illegible]	ND	ND			
2-butoxyethanol		ND	ND		ND	ND		ND	ND			
1,2-diethoxyethane			ND	ND		100				ND		
Ketones												
acetone	BRQL		ND	ND		2.0	ND			[illegible]	2.0	
2-butanone	2.6		ND	ND		1.1	ND			D	1.0	
4-methyl-2-pentanone	10.2		ND	ND		ND	ND			ND		
3,3,5-trimethylcyclohexanone	660	ND	ND		ND	78	ND		ND			
camphor	331	ND	ND		ND	61	ND	ND	ND			
fenchone			ND	ND		ND	ND			ND		

Appendix 4 Table 4

	Site 13 (Leachate)	Site 1^b	Site 5^a	Site 23^a		Site 22		Site 27^b	Site 28^a		RQL^d	Drinking Water Criteria^{e,f}
Sampling Depth		40.1m	10m	8.4m	12.6m	7.2m^c	16.2m^b	23.5m	5.9m	20.1m		
Esters												
propyl propionate		D	ND		ND	ND		ND	ND			
butyl propionate			ND		ND	ND		ND	ND			
diethyl phthalate		D	BRQL		BRQL	ND	(D)^g	ND	BRQL		5.0	
butylmethyl phthalate		D	ND		ND	ND		ND	ND			
di-n or di-isobutyl phthalate	73	D	4.8		8.7	3.0	(D)^g	D	2.7		0.4	
di-n or di-isooctyl phthalate		ND	ND		ND	ND		ND	ND		1.5	
bis-(2-ethylhexyl) phthalate	330	D	ND		ND	20.0	(D)^g	ND	ND		0.5	4.0^f
triethyl phosphate	ND	ND	ND		7.7	ND		ND	ND			
tributyl phosphate		D	ND		ND	ND		ND	ND			
Aromatic Acids												
benzoic acid	D	D	BRQL		BRQL	ND		ND	BRQL			
dimethyl benzoic acid	37	ND	ND		ND	ND		ND	ND			
phenylacetic acid		ND	ND		ND	ND		ND	ND			
butylbenzoic acids	752	ND	ND		ND	ND		ND	ND			
salicylic acids		D	ND		ND	ND		D	ND			
Phenols												
phenol	92	ND	ND		BRQL	3.0		ND	14.5		1.5	2.0^e
cresols	134		ND		ND	ND			ND		3.0	2.0^e
xylenols	376	ND	ND		ND	7.0		ND	ND		2.0	2.0^e
C_3-phenols	214	ND	ND		ND	19.0		ND	ND		2.0	2.0^e
hydroxybiphenol		ND	ND		ND	9.0		ND	ND			
methylene-bis-phenols	840	ND	ND		ND	37		ND	ND			
4,4'-(1-methylethylidene)-bis-phenol		ND	ND		ND	12		ND	ND			
Aromatic Amines												
aniline	ND	ND	ND		3.6	D		ND	ND			1.0^f
N-methylaniline	ND	ND	ND		4.0	ND		ND	ND			
N,N-dimethylaniline		ND	ND		5.8	ND		ND	ND			
Heterocyclic Compounds												
2-or 4-methyl-1,3-dioxolane	D		ND	ND		ND	ND			ND	2.0	
tetrahydrofuran	23.9		ND	ND		6.0	ND			(D)^g	1.0	50.0^f
1,4-dioxane	23.6		ND	ND		4.8	ND			ND	80.0	
dimethyldioxane	13.8		ND									
2-methylthiophene			ND	ND		ND	ND			ND		
1,2,4-trithiolane		D	ND		ND	ND		D	ND			
1,3,5-trithiane		ND	ND		ND	ND		D	ND			
hexathiepane		ND	ND		ND	ND		D	ND			
oxathiolane	200	ND	ND		ND	13.0	ND	ND	ND			
pyrrolidinone, substituted		ND	ND		ND	ND		ND	ND			
pyridine			ND	ND		ND						
methylpyridine	11	ND	ND		ND	3.0		ND	ND			
isoquinoline	ND	ND	ND		ND	ND		ND	ND		0.3	
oxadiazoline, substituted		ND	ND		ND	ND		ND	ND			
benzothiazole		D	4.9		BRQL	D	(D)^g	D	1.4		0.8	
hydroxybenzothiazole	990	ND	ND		ND	127		ND	ND			
mercaptobenzothiazole		ND	ND		ND	ND		ND	ND			
benzothiazolone	ND	ND	0.3		1.1	ND		ND	0.3			
vitavax^h		ND	ND		ND	3		ND	ND			
octamethylcyclo-tetrasiloxane		ND	ND		ND	ND		D	ND			

Appendix 4 Table 4

Sampling Depth	Site 15 (Leachate)	Site 1[b] 40.1m	Site 4[a] 10m	Site 23[a] 8.4m	Site 23[a] 12.6m	Site 25 7.2m[c]	Site 25 16.2m[b]	Site 27[b] 23.5m	Site 28[a] 5.9m	Site 28[a] 24.1m	RQL[d]	Drinking Water Criteria[e,f]
Miscellaneous Sulfur & Nitrogen Compounds												
carbon disulfide			ND	ND		ND	ND			ND	1.0	
dimethyl disulfide	ND		ND	ND		ND	ND			(D)[g]		
diethyl disulfide			ND	ND		ND	ND			ND		
acrylonitrile			ND	ND		ND				ND		0.07[f]
nonamide		ND	ND		ND	ND		ND	ND			

Notes: Location of sampling sites shown in Figure 6.

[a] Analyzed by Stanford University.
[b] Analyzed by Mann Testing Laboratories.
[c] Analyzed by the Ontario Ministry of the Environment.
[d] RQL means Reliable Quantification Limit of the analytical method.
[e] Ontario Ministry of the Environment Drinking Water Objectives (where available).
[f] New York State Proposed Drinking Water Toxics Standards, January 1985 (where available).
[g] Found at another depth in the same borehole.
[h] Vitavax is 5,6-dihydro-2-methyl-N-phenyl-1,4-oxathiin-3-carbonoxamide.

BRQL means Detected, but Below Reliable Quantification Limit.
D means the compound was detected but the amount not determined.
ND means the compound was searched for; if present, the amount is below the detection limit.

Where no data are given in this table, the presence or absence of the compound was not reported by the laboratory.

APPENDIX 5

LOCATION OF SAMPLING SITES FOR AIR ANALYSES

(Shown in Figure 11)

Site Number	Description
1.	A 10.2cm diameter landfill gas well drilled to a depth of 9.8 metres by Conestoga-Rovers & Associates Limited (CRA) in October 1982 for the gas collection and flaring experiments. The well is located on the south side of the landfill beside an access road about one half the way up the slope of the mound.
2.	A 1.27cm diameter landfill gas probe installed to a depth of 6.1 metres within 15.2cm of Site 1.
3.	Two 1.27cm diameter landfill gas probes installed to depths of 3.05 metres and 7.6 metres and located 9.1 metres south of Site 1.
4.	A 1.27cm diameter landfill gas probe installed to a depth of 3.05 metres and located 18.3 metres to the south of Site 1.
5.	A 1.27cm diameter landfill gas probe installed to a depth of 7.6 metres and located 18.3 metres to the south of Site 1.
6.	A 1.27cm diameter landfill gas probe installed to a depth of 4.6 metres and located 32 metres to the south of Site 1.
7.	A 7.6cm 'gooseneck' vent installed to a depth of 1.2 metres below the surface of the landfill cover for passive venting of methane gas and connected by a gravel trench to the leachate collection drains. It is the fourth vent located east of the fire training facility.

8. A 7.6cm diameter 'gooseneck' vent installed to a depth of 1.2 metres below the surface of the landfill cover for passive venting of methane gas. It was used as a gas probe for the gas collection and flaring experiment and is located 45.7 metres south of Site 1.

9. A 7.6cm diameter 'gooseneck' vent installed to a depth of 1.2 metres below the surface of the landfill cover for passive venting of methane gas. It is the third vent located west of the railway track and it is connected by a gravel trench to the leachate collection drains.

10. A 7.6cm diameter 'gooseneck' vent installed to a depth of 1.2 metres below the surface of the landfill cover for passive venting of methane gas. It is the second vent located west of the railway track and it is connected by a gravel trench to the leachate collection drains.

11. A 7.6cm diameter 'gooseneck' vent installed to a depth of 1.2 metres below the surface of the landfill cover for passive venting of methane gas. It is the vent located closest to the railway track on the southeast corner of the landfill.

12. A 1.27cm diameter landfill gas probe installed to a depth of 3.05 metres and located 47.5 metres to the east of Site 1.

13. A Waterloo Research Institute (WRI) (shown as site 6 in Figure 6 and site UW 26-1 in Figure 7) borehole located on the northwest corner of the landfill where the solidification plant operated. The high gas pressure and methane concent-rations observed in this borehole indicates that it is intercepting wastes within the mound rather than ground-water.

14. This site, used for high-volume sampling of particulates, is located at the northeast tip of the landfill at the Redhill Creek and the railway track.

15. This site, used for Tenax tube and high-volume samplings, is located at the southwest edge of the landfill beside the fire training facility.

16. This site, used by Mann Labs for Tenax tube sampling, is located 236 metres west of the landfill in the public works yard.

17. This site, used by Mann Labs for Tenax tube sampling, is located 300 metres south of the landfill on Hempstead Drive, on the west side of Greenoch Road.

18. This site, used by Mann Labs for Tenax tube sampling, is located 739 metres southwest of the landfill at Upper Ottawa Street and Unsworth Drive.

19. This site, used by Sciex, is located 500 metres west of the landfill at Stone Church Road and Upper Ottawa Street.

20. This site, used by Sciex and Mann Labs, is located at Blessed Kateri Tekakwitha School, 419 metres west of the landfill.

21. This site, used by Sciex, is located 10 metres west of the landfill gate on the west side of the landfill.

22. This site, used by Mann Labs for Tenax tube sampling, is located 600 metres northwest of the landfill, on Limeridge Road, 20 metres east of Upper Ottawa Street.

23. This site, used by Mann Labs for Tenax tube sampling, is located 469 metres north of the landfill at Limeridge Road and Lennox Street.

24. This site, used by Sciex, is located 780 metres northeast of the landfill at Limeridge Road and the railway track.

25. This site, used by Mann Labs for Tenax tube sampling, is located 820 metres northeast of the landfill on Albion Falls Blvd.

26. This site, used by Sciex, is located 600 metres northeast of the landfill on Arbour Road.

27. This site, used by Mann Labs for Tenax tube sampling, is located 400 metres east of the landfill at Mount Albion Park on the north side of Stone Church Road.

* Please note that Sites 28 - 41 are control sites not shown on Figure 11.

28. This residential site, used by Sciex, is located 600 metres north of the landfill at the intersection of Limeridge Road and Upper Kenilworth Avenue.

29. This site, used by Sciex, is located 14 kilometres west of the Upper Ottawa Street landfill at Shavers Road and Highway 2 near the Ancaster landfill.

30. This site, used by Sciex, is located 14 kilometres west of the Upper Ottawa Street landfill at the gate of the Ancaster landfill.

31. This residential site, used by Sciex and Mann Labs, is located 6.5 kilometres west of the landfill at the reservoir at Stone Church Road and Garth Road.

32. This residential site, used by Sciex, is located 6.3 kilometres west of the landfill at King Ridge Plaza on Limeridge Road West, one block east of Garth Street.

33. This residential site, used by Sciex, is located 5.2 kilometres west of the landfill on Chester Avenue near West 5th and Stone Church Road.

34. This residential site, used by Sciex, is located 5.3 kilometres north of the landfill at King Street East and Gage Avenue.

35. This industrial site, used by Sciex, is located 6.8 kilometres north of the landfill at Burlington Street East and Stapleton Avenue near Kenilworth Avenue.

36. This industrial site, used by Sciex, is located 6.1 kilometres north of the landfill at Mahony Park near Barton Street East and Parkdale Avenue.

37. This industrial site, used by Sciex, is a rectangular route (Barton St. East, Ottawa Street, Burlington Street and Parkdale Avenue) sampled by the TAGA mobile laboratory. The route is between 5.7 and 7.2 kilometres north of the landfill.

38. This downtown commercial site, used by Mann Labs for Tenax tube sampling, is located 7.1 kilometres northwest of the landfill at King and James Streets.

39. This residential site, used by Mann Labs for Tenax tube sampling, is located 5 kilometres west of the landfill on Stone Church Road between Upper James Street and West 5th.

40. This residential site, used by Mann Labs for Tenax tube sampling, is located 2.3 kilometres west of the landfill at Stone Church Road and Upper Sherman Avenue.

41. This residential site, used by Mann Labs for Tenax tube sampling, is located 4.2 kilometres southwest of the landfill at Highway 53 (Rymal Road) and Upper Wellington Street.

APPENDIX 6

MEMBERSHIP OF THE ADVISORY HEALTH GROUP

	Term
Chairman	
Dr. William M. Goldberg, M.D. Head, Service of General Medicine and Head, Service of Behavioural Medicine St. Joseph's Hospital Clinical Professor, McMaster University Hamilton, Ontario	1981-1986
Dr. David C.F. Muir, M.D. Director Occupational Health Program McMaster University Hamilton, Ontario	1981-1986
Dr. Michael T. Newhouse, M.D. Clinical Professor of Medicine McMaster University Head of Firestone Regional Chest and Allergy Unit St. Joseph's Hospital Hamilton, Ontario	1981-1986
Dr. Andrew C. Harper, M.D. formerly at the Department of Clinical Epidemiology and Biostatistics McMaster University Hamilton, Ontario	1981-1985
Dr. Michael R. Achong, M.D. Hamilton, Ontario	1981-1982

APPENDIX 7

REFEREES ENGAGED TO REVIEW HEALTH STUDIES

Report on the Survey of the Health of Landfill Workers, 1984

Dr. Philip J. Landrigan	Department of Human and Health Services, Centres for Disease Control, National Institute for Occupational Health and Safety
Dr. Ian Munroe	Canadian Centre for Toxicology
Dr. Marvin A. Schneiderman	Formerly with the National Cancer Institute
Dr. Walter O. Spitzer	Department of Epidemiology and Biostatistics, McGill University
Dr. Steven D. Walter	Department of Clinical Epidemiology and Biostatistics, McMaster University

Report on the Survey of the Health of Persons Living Near the Landfill, 1985

Dr. Philip Cole	Department of Epidemiology, University of Alabama at Birmingham
Dr. Philip J. Landrigan	The Mount Sinai Medical Centre.
Dr. Marvin A. Schneiderman	Formerly with the National Cancer Institute.
Dr. Steven D. Walter	Department of Clinical Epidemiology and Biostatistics, McMaster Univertsity.

APPENDIX 8

STUDIES PREPARED FOR THE UPPER OTTAWA STREET LANDFILL SITE STUDY COMMITTEE

1. Frank Crossley, The Effects of the Upper Ottawa Street Landfill Site on Groundwater and Surface Waters, February, 1982.
2. Sciex, Report on Air Quality Surveys at the Upper Ottawa Street Landfill Site, February, 1982.
3. Andrew Harper, Final Report on the Feasibility of Conducting Health Studies, April, 1982.
4. Mann Testing Laboratories Ltd., Reports of Chemical Characterization by GC-MS Spectrometry, May and August, 1982.
5. Mutatech Inc., Report on Laboratory Validation of Field Experiments Carried out at the Upper Ottawa Street Landfill Site, August, 1982.
6. Waterloo Geophysics Inc., A Preliminary Geophysical Study at the Upper Ottawa Street Landfill Site, September, 1982.
7. Mann Testing Laboratories Ltd., Chemical Analysis of Core Samples From Boreholes #2 and #4, October, 1982.
8. Mutatech Inc., Report on the Analysis of Air Particulates and Leachates from the Upper Ottawa Street Landfill for Mutagenicity in the Ames Tests, November, 1982.
9. Mann Testing Laboratories Ltd., Analysis of Pre- and Post-Flare Gases from the Test Well on the Upper Ottawa Street Landfill Site, December, 1982.
10. Mann Testing Laboratories Ltd., Tenax Sorbent Tube GC-MS Analysis of Air On and Around the Upper Ottawa Street Landfill Site, December, 1982.
11. I.K. Barker, Department of Pathology, University of Guelph. Reports on Pathology and Pesticide Analysis of Animals Trapped On and Near the Upper Ottawa Street Landfill, December, 1982.
12. Mann Testing Laboratories Ltd., Chemical Analysis of Pre- and Post-Flare Gases, January, 1983.
13. Environ Corporation, Preliminary Summary of the Inherent Toxic Properties of Selected Substances Tentatively Identified at the Upper Ottawa Street Landfill, January - February, 1983.

14. Sciex, Final Report on Air Quality Surveys at the Upper Ottawa Street Landfill Site, January, 1983.

15. Mann Testing Laboratories Ltd., Quantification of Selected Volatile Organics at the Upper Ottawa Street Landfill Site, February, 1983.

16. Mann Testing Laboratories Ltd., Quantification of Selected Volatile Organics at the Upper Ottawa Street Landfill Site, February 28, 1983.

17. Conestoga-Rovers & Associates Limited, Feasibility Study of Landfill Gas Control at the Upper Ottawa Street Landfill, March, 1983.

18. J.A. Cherry, and J.F. Barker, Hydrogeological Investigations of the Upper Ottawa Street Landfill Site: A Progress Report for the Period April 1982 to February 1983, Institute of Groundwater Research at the University of Waterloo, March 17, 1983.

19. J. J. Ryan, Correspondence "Re: Analysis of Two Leachate Samples for Dioxins and Furans," prepared for the Upper Ottawa Street Landfill Site Study Committee by the Health Protection Branch, Health and Welfare Canada, May 11, 1983.

20. R. F. Willes, Toxicity Profiles for Selected Compounds. November, 1982 to June, 1983.

21. Mutatech Inc., Report: Ames Tests on Gases Emanating from Vents On the Upper Ottawa Street Landfill, September 1983.

22. Hamilton Opinion Research Centre Ltd., Final Progress Report of Workers Survey, May 1984.

23. J. A. Cherry, J. F. Barker, R. J. Blackport, and J. E. Barbash, Hydrogeological Investigations of the Upper Ottawa Street Landfill Site in Hamilton, Ontario. (Final Report), Institute of Groundwater Research at the University of Waterloo, October, 1984.

24. Hamilton Opinion Research Centre Ltd., Final Report on Residents Health Study, January, 1985.

25. Mann Testing Laboratories Ltd., Monitoring of Leachate and Red Hill Creek at the Upper Ottawa Street Landfill Site: Reports 1-4. September, 1983. October, 1984. January and March, 1985.

26. Mann Testing Laboratories Ltd., Upper Ottawa Street Landfill Site Soil Analysis, August 16, 1985.

27. Mann Testing Laboratories Ltd., Reports on Ambient Air Analysis of Landfill and Peripheral Sites: December 1982; November 15, 1983; October 18, 1984; December 31, 1984; January 21, 1985 and August 21, 1985.

28. Mann Testing Laboratories Ltd., Analysis of 4 Leachate Samples prepared for the Upper Ottawa Street Landfill Site Study Committee, October 18, 1984.

29. Mann Testing Laboratories Ltd., Analysis of Outgassing from Test Probes, Bore Hole and Test Well, November 1, 1985.

30. Mann Testing Laboratories Ltd., Sampling and Analysis of Polynuclear Aromatic Hydrocarbons, December 10, 1985.

31. Mann Testing Laboratories Ltd., Analysis of Three Polynuclear Aromatic Hydrocarbons From High-Volume Filters, December 19, 1985.

32. C. Hertzman, J. Singer, J. Highland and M. Hayes, Report of the Workers Health Study of the Upper Ottawa Street Landfill Site Study, 1985.

33. C. Hertzman, J. Singer, J. Highland, and M. Hayes, Residents Health Study Report for the Upper Ottawa Street Landfill Site Study, 1986.

34. CJB Associates Inc., Atmospheric Dispersion Study of the Upper Ottawa Street Landfill Site, February, 1986.

35. Environ Corporation, Upper Ottawa Street Landfill Risk Assessment - Feasibility Study, May 20, 1986.

APPENDIX 9

BIBLIOGRAPHICAL NOTES ON COMMITTEE MEMBERS

Arthur Bourns is an organic chemist and formerly president of McMaster University.

Dennis McCalla is a biochemist and currently Vice-President, Health Sciences at McMaster University.

Sandy McCallion is a steelworker in Hamilton.

James Osbaldeston is a family physician practicing in Hamilton.